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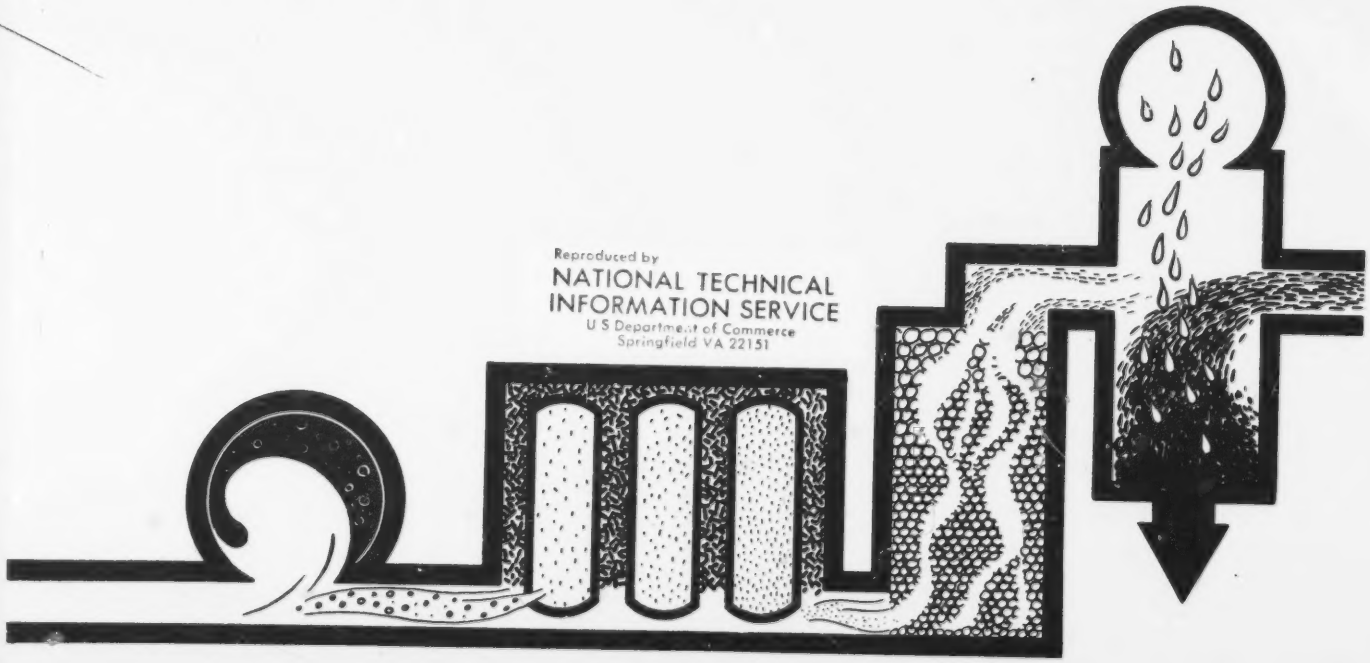
Amenability of Reverse Osmosis Concentrate to Activated Sludge Treatment



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Pilot scale tubular and spiral wound Reverse Osmosis (RO) units were utilized to establish the feasibility of renovating municipal sewage. Results indicated that prior treatment with ferric chloride and alum will be necessary even when utilizing the tubular RO system. RO produced an approximate 100 mg/l TDS of inorganic ions in the effluent, but an estimated 40 to 50% of the soluble organic material permeated the membranes at high feed water recoveries. Approximately 70% of the organic material passing the membrane was ethanol, but other organics may pass through the membranes from other sewages. 92% water recovery rates, with no precipitation problems in the RO concentrate, were achieved, but RO product waters would require further treatment for organic removal prior to discharge. The feasibility of biodegrading RO concentrates was also established, with TOC removals of 87 to 93% obtained in 4-10 hours, depending upon the suspended solids level maintained. (Lowry-Texas)

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AMENABILITY OF REVERSE OSMOSIS CONCENTRATE TO ACTIVATED SLUDGE TREATMENT

by

Rex Chainbelt Inc.
The Ecology Division
Milwaukee, Wisconsin 53201

for the

ENVIRONMENTAL PROTECTION AGENCY

Project #17040 EUE

July 1971

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ABSTRACT

This report documents a laboratory-scale feasibility study for the treatment of domestic sewage. The objective of the study was to produce potable water from chemically clarified sewage via reverse osmosis (RO) and to determine the amenability of the RO concentrate to biological treatment.

Pilot-scale tubular and spiral wound RO units were utilized in this study. It was determined that chemical clarification of the raw sewage was necessary even with the tubular RO systems. The chemicals recommended for the pretreatment (based on jar tests) were ferric chloride and alum. Reverse osmosis produced a water of excellent quality with regard to inorganic ions. However, a significant amount of the dissolved organic materials passed through the cellulose acetate membranes, necessitating further upgrading of product water for potable use. Qualitative investigations on the RO permeate indicated that 70% of the organic matter permeating through the CA membranes from Milwaukee sewage was apparently ethanol (C_2H_5OH).

Bench-scale activated sludge feasibility tests conducted on the RO concentrate indicated that it was feasible to treat it biologically. Soluble TOC removals of 87 to 92% in 4 to 10 hours of aeration along with good settling characteristics for MLSS concentrations up to 6000 mg/l were achieved. A treatment schematic that will provide potable water at 93% recovery and would also reduce the pollutional discharge to streams was proposed.

This report was submitted in fulfillment of Grant No. 17040 EUE under the partial sponsorship of the Environmental Protection Agency.

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SECTION I

CONCLUSIONS

This study has demonstrated the potential use of Reverse Osmosis in the treatment of domestic waste waters. An excellent quality effluent water was produced relative to inorganic ion rejection. However, the product water from RO must be further upgraded for potable use since some of the soluble organic material passes through the RO membranes. It was also demonstrated that it is feasible to treat the RO brines biologically. Specific conclusions which can be drawn from this study are:

1. Prior chemical treatment of the raw sewage will be necessary even when tubular RO systems are utilized.

2. Ferric chloride and alum were concluded to be the most suitable chemicals for the pretreatment of raw sewage.

3. Reverse osmosis produced an excellent quality product water with regard to inorganic ions (approximately 100 mg/l TDS).

4. Approximately 40-50% of the soluble organic material permeated through the cellulose acetate membranes at high feed water recoveries.

5. The RO product waters will have to be post treated to meet the water quality standards for maximum organic material in potable waters.

6. Qualitative investigations on the RO permeate indicated that approximately 70% of the organic matter permeating through the RO membranes was apparently ethanol (C_2H_5OH) for Milwaukee sewage. However, organics passing through the RO membranes may be appreciably different for other sewages.

7. Significantly less fouling of the membranes was observed with chemically clarified sewage as compared to settled sewage through laboratory recycling test procedures.

8. Water recovery rates of 92% were achieved in the laboratory without any precipitation problems in the RO concentrate.

9. It was demonstrated that the RO concentrates can be successfully treated biologically. TOC removals in the range of 87 to 93% were obtained in 4 to 10 hours aeration time depending upon the suspended solids level maintained.

10. Metallic ion concentrations in the concentrates were found to be well below levels, toxic to activated sludge biota.

11. Mixed liquor suspended solids concentrations of up to 6000 mg/l could be maintained with good settling characteristics.

12. An average oxygen uptake rate that can be utilized for design purposes was 30 to 40 mg/l/hr.

SECTION II

RECOMMENDATIONS

Based on the results of this study, it is recommended that:

1. A split flow treatment scheme consisting of chemical treatment, reverse osmosis, activated carbon and ozone oxidation be utilized for the treatment of domestic sewage. The above combination of treatment concepts is expected to provide high recovery of reusable and potable water as well as reduce pollutant discharges to streams.

2. A prototype scale RO system be constructed and that the field evaluations be conducted in accordance with the proposed split flow treatment scheme. Also, special emphasis be placed on the evaluation of the flux decline characteristics due to the presence of soluble organic material.

3. The RO concentrates be treated via activated sludge process and a prototype unit be constructed to substantiate the laboratory findings in the field on a continuous flow basis.

4. Post treatment investigations on RO permeates be continued on sewages from various treatment plants other than Milwaukee.

5. Hollow fiber RO configuration be evaluated and compared to other RO configurations for the treatment of chemically clarified domestic waste waters.

6. A detailed cost analysis for using reverse osmosis to treat municipal waste waters be prepared.

SECTION III

INTRODUCTION

The ever increasing demand for fresh water combined with an increased emphasis on a more complete abatement of water pollution has forced the water purveyors of the nation to study ways and means of utilizing our waters more efficiently. A logical way of improving this efficiency is through multiple use of the water supplies.

To achieve this objective, the conventional waste treatment practices must be modified and/or supplemented with advanced wastewater treatment technology that will provide reusable and potable water. The domestic wastewaters are normally dilute organic-bearing wastes and typically have dissolved solids concentrations in the range of 500-1500 mg/l. The primary concern in the application of the newer technology is the removal of nutrients, dissolved mineral salts, oxygen-demanding organics and undesirable bacteria and viruses presently being discharged as a result of incomplete conventional waste treatment. Removal of these contaminants can be accomplished with a variety of processes such as reverse osmosis, activated carbon, ion exchange, biological and chemical oxidation and disinfection. Most of these processes except reverse osmosis can remove only a portion of the pollutants. For example, organic contaminants can be adsorbed over activated carbon but dissolved inorganics are not; while ion exchange can remove the dissolved inorganics, the soluble organics pass through. However, reverse osmosis is a process which is capable of separating the dissolved organics and inorganics from an aqueous solution in addition to the removal of bacteria and viruses. The promising potential of the reverse osmosis process in the waste treatment area has consistently been described in recent literature (1, 2, 3, 4, 5). The continual development and refinement of RO membranes and hardware has now made it possible to study the feasibility of utilizing this process for municipal wastewater treatment. The specific objectives of this study were:

1. To establish the pretreatment steps required to allow RO to function efficiently when treating municipal wastewaters.

2. To determine whether the waste concentrate from the RO process is amenable to activated sludge treatment.

3. To evaluate the quality of the RO product water with regard to its reuse as a potable water supply.

To accomplish the stated objectives of the project, the test program was divided into the following five phases:

1. Pretreatment investigations

2. RO evaluations

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3. Biological system evaluations

4. Permeate quality investigations

5. Preliminary cost information

Raw sewage samples from various treatment plants in the Milwaukee area were utilized in this study. The feasibility evaluations in the various phases were conducted with laboratory scale pilot plant equipment. Based on the results of the laboratory scale investigations, a treatment schematic was developed and proposed for a large scale field program.

SECTION IV

LITERATURE REVIEW

There has been a limited amount of work done in the area of reverse osmosis application to municipal wastewater treatment. Mostly, it has been in the form of pilot plant investigations. Initial investigations in this area were started when preliminary tests by Aerojet General Corporation in 1962 indicated that the cellulose acetate membrane was an effective barrier for both organic and inorganic solutes. Subsequent work was conducted on filtered municipal secondary effluent with a flat plate test cell (6). The results indicated greater than 95% removals of total dissolved solids (TDS) and chemical oxygen demand (COD). However, severe flux decline problems were experienced. Further pilot plant testing was conducted at Pomona, California with the spiral-wound configuration on secondary and activated carbon treated effluents by Gulf Environmental Systems under various contracts sponsored by EPA (7). Results of these tests again showed high organic and inorganic solute rejections at lower feed water recoveries. However, significant fouling of the membranes was again noticed due to the soluble organic material present in the filtered secondary effluent. Various flushing and membrane cleaning techniques were utilized for reducing the membrane fouling and for restoring the flux losses. A cleaning technique utilizing an enzyme-based detergent was considered to be the most effective.

Laboratory scale reverse osmosis tests on municipal wastewaters were conducted by Aerojet-General Corporation (8). These tests were conducted in assemblies representing two different membrane geometries: sheet and tubular. Behavior and response of the reverse osmosis process to carbon-treated secondary effluent, alum-treated secondary effluent, secondary effluent, alum treated primary effluent, raw sewage and digester supernatant were evaluated. High removals of dissolved organics and inorganics were reported. The principal cause of flux decline was attributed to the membrane fouling by finely dispersed solids and the effect of the dissolved organic substances was considered to be of lesser relative importance. The effects of the flocculent, dispersant, chelating, enzyme and acid on reducing product water flux decline were compared. Pretreatment of the municipal wastewater feed by flocculation with alum, followed by rapid sand filtration was considered to be the most effective of all the preconditioning methods studied. Evaluation of the flat-plate configuration in the treatment of municipal wastewaters was also made at Lebanon, Ohio by the EPA staff. The results of these pilot plant investigations have been well summarized by Smith, et al (9). It was concluded that excellent separation of both the inorganic and organic contaminants could be achieved in treating the secondary or carbon-treated effluents by reverse osmosis. However, organic fouling of the membranes was experienced in all runs and was considered the principal cause of the flux declines that occurred. It was clearly indicated that for reverse osmosis to become competitive, it will have to be employed near the primary end of the treatment train. The need for the evaluation of

the proper pretreatment requirements preceding RO and an investigation of the treatment and disposal of the concentrated brines was clearly indicated. Also, the performance of the tubular RO systems needed to be evaluated towards the primary end of the treatment train because of their capability of handling larger amounts of suspended material. It is apparent from the above discussion that many technical areas require further investigation in order to successfully apply reverse osmosis to the treatment of municipal wastewaters.

SECTION V

TEST EQUIPMENT AND PROCEDURES

The equipment and procedures employed in the various phases of this project, except in the permeate investigation phase, are described below. The description of the apparatus for the permeate investigation phase is presented in Appendix III. The laboratory procedures utilized for all analyses except TOC and atomic absorption were performed in accordance with Standard Methods (10). The TOC and AA analyses were performed in accordance with the guidelines published by EPA (11) and the instrument manufacturer (12, 13).

Pretreatment Equipment

Jar test procedures were utilized for studying the chemical flocculation of the raw wastes from various treatment plants during the pretreatment investigations phase. Flocculation procedure consisted of one minute rapid mix @ 100 rpm followed by five minutes of slow mixing at 10-15 rpm with a Phipps and Bird stirrer. This was followed by one hour of sedimentation time. The optimum chemical dosages were determined on the basis of the reduction in the turbidity of the flocculated and settled effluent. A Hellige turbidimeter (Model 925A) was utilized for all turbidity measurements.

RO Equipment

The basic elements of a reverse osmosis system are shown in Figure 1. It may be seen from this figure that the RO process produces two liquid streams. One stream, highly concentrated with the materials originally present in the feed stream, is called the concentrate or brine, while the water which has passed through the membrane is called the permeate or product water. The basic elements shown in Figure 1 are common to all reverse osmosis systems. The essential difference between various system configurations lies in the method of packaging the membranes.

There are only three forms which are commercially available in large quantities. These are tubular, spiral-wound and the hollow-fiber membranes. These systems have been described in great detail in earlier literature (14). However, since this study was made with the tubular and spiral-wound RO systems, some pertinent remarks about these are in order.

In tubular systems, the cellulose acetate membrane is formed in a tubular shape generally one-half inch in diameter and several feet long. There are a number of different tubular systems which are commercially available. In some systems the membrane is cast directly onto a supporting tube, while in others the membrane is cast separately

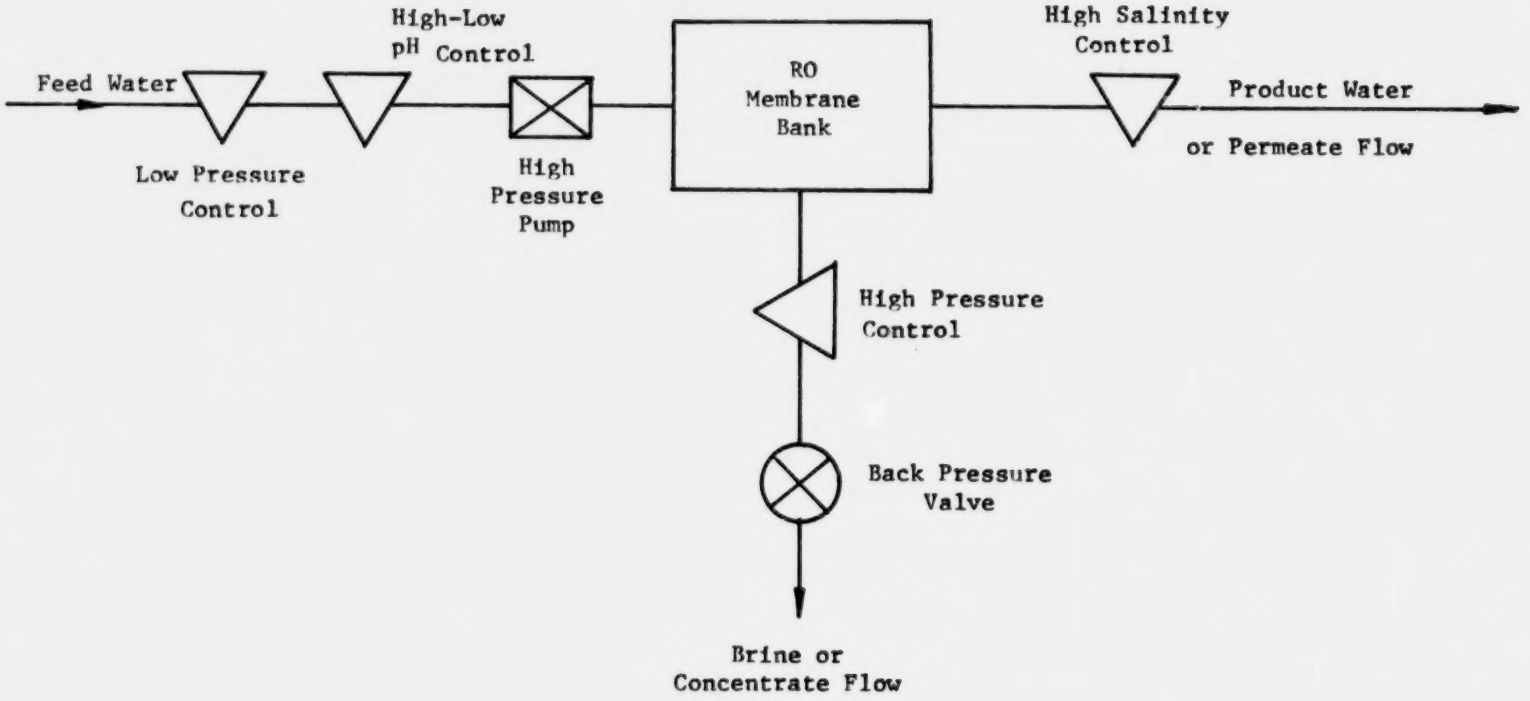


FIGURE 1

BASIC ELEMENTS OF A REVERSE OSMOSIS SYSTEM

and later inserted into a supporting tube. Some suppliers utilize the supporting tubes made of porous fiberglass material and the tubes serve as the pressure vessel. Others have supporting tubes made out of some sort of plastic or cardboard and a separate pressure vessel is provided. The individual bundles of tubes (modules) are then grouped together to form the membrane bank portion of the RO System.

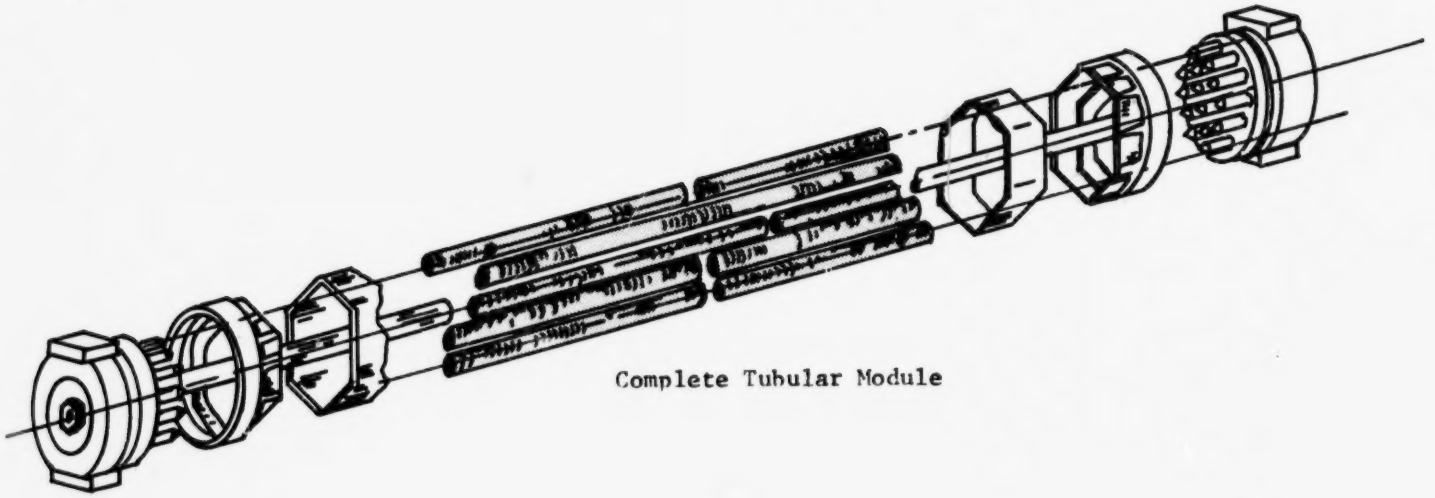
The tubular system marketed by Calgon-Havens Industries was utilized in this study. Modules of two membrane types were used. The looser membrane was designated as Type 300 or 310 with lower salt rejections and higher flux rates, while the tighter membrane was designated as Type 500 or 510 with higher salt rejections and lower flux rates. In the earlier part of the study the older type modules (300 and 500) were utilized for flux decline studies while later evaluations of the water quality data were performed with the new type modules (310 and 510). The essential difference between these modules was in the method of inter-connection of the individual tubes within each module. The tubes in the old module were connected by separate turn arounds at both ends while for the new module, these were connected internally by means of a molded integral head (sealed by O-rings between the tubes and the molded head). Each module consisted of 18 porous fiberglass tubes. The membrane is cast onto the inside of the tubes. The porous fiberglass tube acts both as the membrane support and the pressure vessel. Each module contains an effective membrane area of 16.9 sq ft. A sketch of the tubular module and a single tube is shown in Figure 2. Each new module (310 & 510) was also equipped with 18 turbulence promotors (also called volume displacement rods) inside the tubes to minimize the concentration polarization effects by increasing the effective velocity through the tubes.

A limited amount of RO data was also obtained with the spiral-wound configuration. This configuration has the advantage of a high membrane area to volume ratio. The spiral wound module utilized in this study is marketed by Gulf Environmental Systems. The membrane used was a newly developed high flux membrane. The module in this system consists of one or more leaves wrapped around a product water take-off tube. These leaves consist of the membrane, a porous, incompressible product water side backing material, and a brine side flow spacer. The membrane is bonded along the two sides, at the end, and around the product water tube, forming a sealed envelope that encloses the backing material except at the product water tube open end. The brine side flow spacer is placed on the membrane, and several layers are then wrapped around the product water tube to form a cylindrical module. Modules are then placed in a suitable pressure vessel. The modules utilized in the study contained a useful membrane area of 50 sq ft. A spiral wound module is shown in Figure 3.

A flow diagram of the pilot RO system utilized is shown in Figure 4.

Single Tube

Turbulence
Promotor Rod



Complete Tubular Module

FIGURE 2

TUBULAR CONFIGURATION

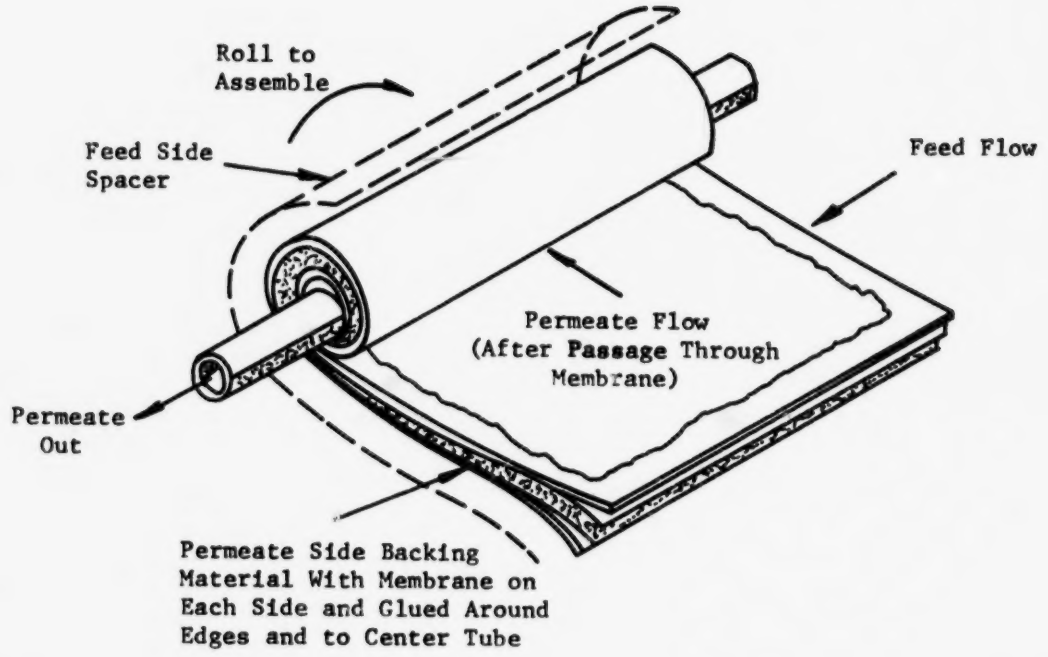


FIGURE 3

SPIRAL WOUND CONFIGURATION

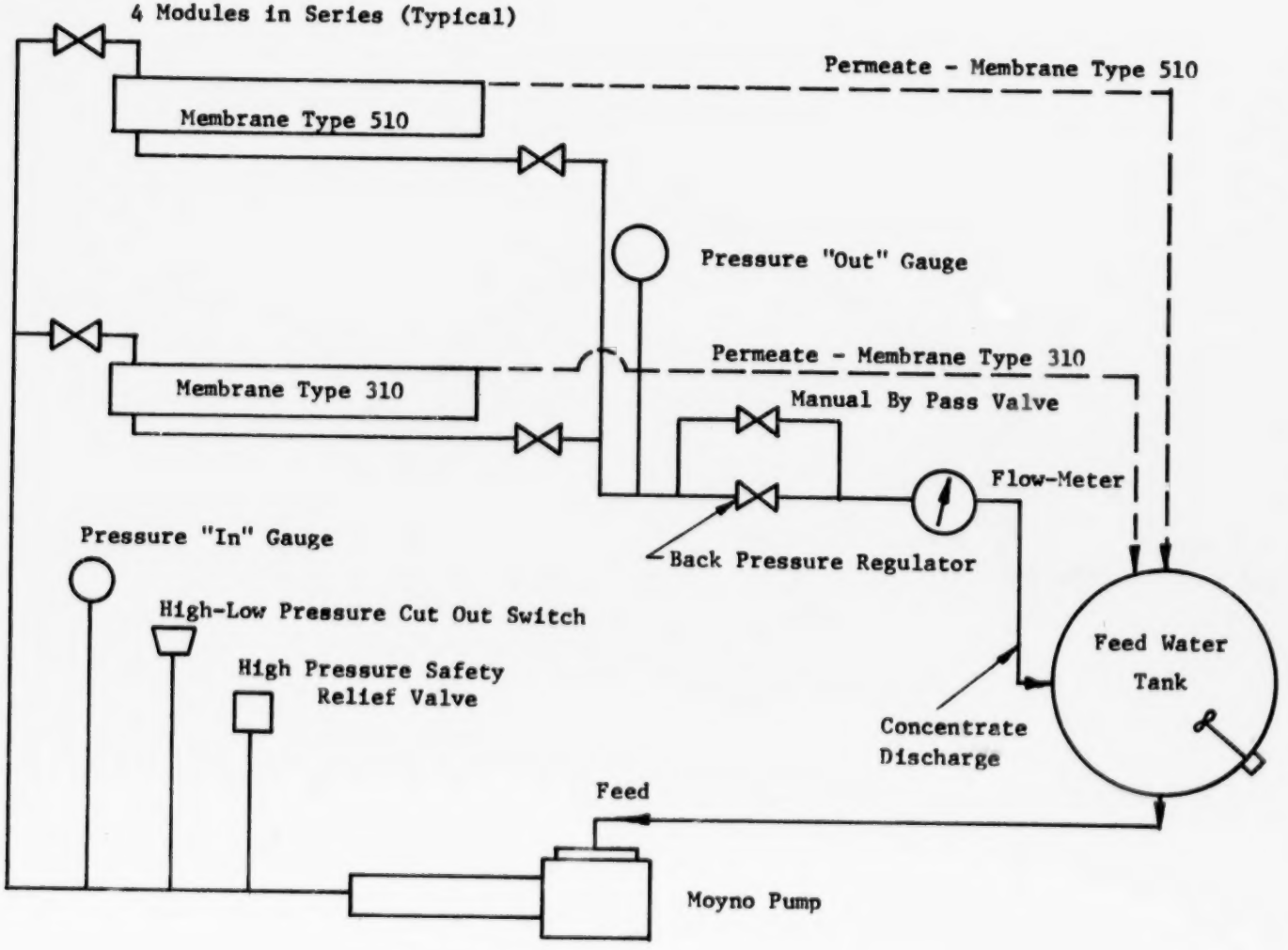


FIGURE 4

SCHEMATIC FLOW DIAGRAM FOR EXPERIMENTAL RO UNIT

The system consists of feeding the wastewater through the modules under a positive head by a Moyno pump. The pump speed is controlled by a variable drive and this controls the pump flow rate. A half-inch diameter stainless steel coil using a recirculation of cold tap water was incorporated in the feed tank to control the feed water temperature to approximately 70°F.

In a typical experiment the pretreated waste water was pumped to the membrane bank from the feed water tank. Both the concentrate (brine) and the permeate (product water) were recirculated to the feed tank. Measurements were recorded for TDS, temperature, pressure, pH and flow rates for the feed, brine, and product streams. Composite permeate samples of the individual membrane types were obtained at the low pressure end of each module row for desired laboratory analysis. In cases where a concentrate stream at higher feed water recovery level was desired, the concentrate was continuously recirculated to the feed tank while the permeate was wasted until the desired recovery level was achieved.

For designing reverse osmosis systems at high feed water recovery levels, the generally recommended module arrangement is shown in Figure 5. This consists of three banks of modules connected in series. Within each bank the modules are connected in parallel. Each bank has a decreasing number of modules to compensate for the product water which has been removed and still maintain turbulent flow conditions. The product water TDS would be highest in bank 3 since approximately 90% of the raw water has been removed and the TDS in the influent to bank 3 is approximately four times as high as the influent to bank 1. Overall salt rejection when the product water streams from various banks are blended should be in the 80% to 90% range.

For the experiments undertaken during this study, the feed water recoveries attainable from the pilot RO unit without recycling of the brine ranged between 20 and 40% depending upon feed flow, type of membrane and the membrane area utilized. In order to evaluate the water quality data at higher feed recovery levels, a computer program available at Rex Chainbelt, Inc. was utilized. The computer program utilizes the actual data obtained at the lower feed water recoveries of the test unit and enables an approximate prediction of the product and brine water qualities at higher recoveries. The program is applicable for any module configurations similar to that shown in Figure 5 and for any number of membrane banks that may have to be utilized to achieve the desired recovery level.

Activated Sludge Experiments

The biological oxidation experiments were conducted in four rectangular ten-liter plexiglass units approximately 7" x 10" x 12" (15). Each unit was equipped with one inch diameter spherical air stones. Air was supplied from the plant air header carrying a pressure of up to 100 psig. The air flow was controlled to each of the units through a needle valve. No attempt was made to measure the air volumes to the units. Conditions

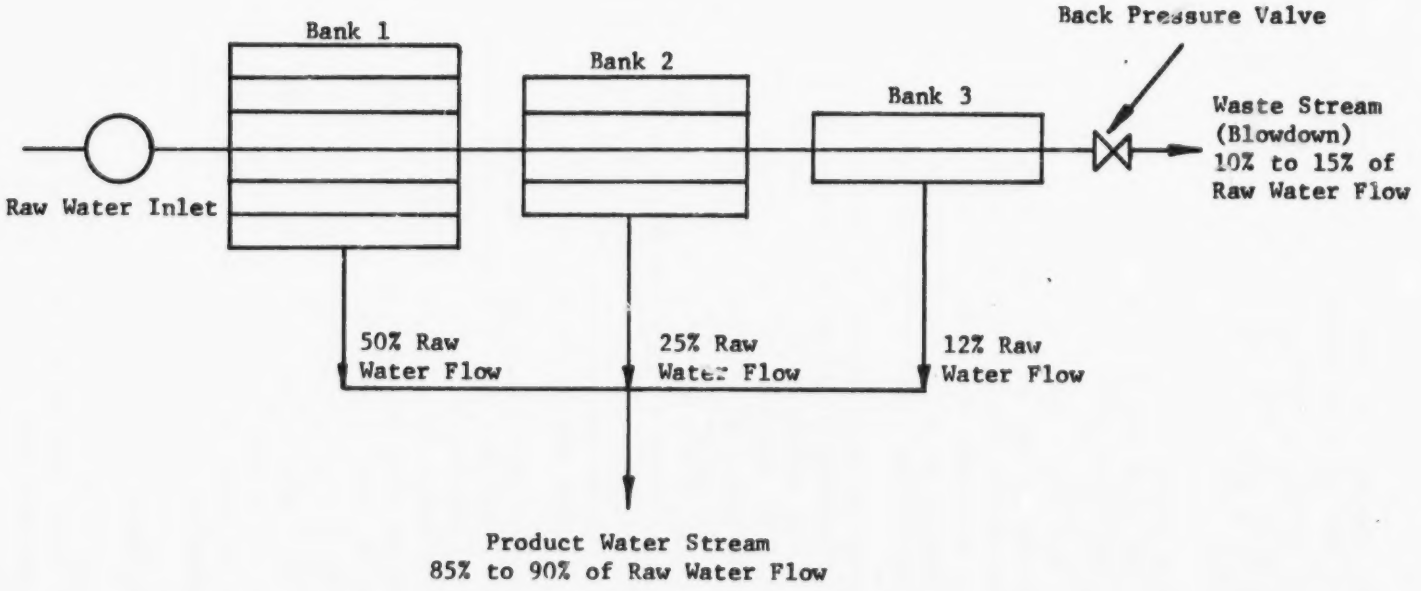


FIGURE 5

RECOMMENDED MODULE ARRANGEMENT FOR REVERSE OSMOSIS

were adjusted to ensure sufficient dissolved oxygen only.

The activated sludge (A.S.) feasibility and design information was obtained by the batch kinetic procedures described by Boyle and Polkowski (16) and based on the work done by McKinney (17) and Eckenfelder (18). Briefly, the procedure consists of acclimating the activated sludge biota to the wastewater for periods up to four weeks so that sufficient sludge is accumulated to operate several aeration reactors at various mixed liquor solid levels. Normally the reactors are set up in such a fashion that various combinations of high and low substrate, high and low solids and one reactor in the endogenous phase can be operated. Total Organic Carbon (TOC), mixed liquor suspended and volatile suspended solids, oxygen uptake rates, pH and settling rates were recorded at frequent time intervals on samples drawn from various reactors.

SECTION VI

TEST RESULTS & EVALUATIONS

Pretreatment Investigation

Raw sewage samples were obtained from six different sewage treatment plants in the Milwaukee area. The raw sewage characteristics of these wastes for the month of May, 1970 are shown in Appendix I (actual plant data). The waste characteristics varied over a wide range. The average BOD ranged from 64 to 296 mg/l. Grab samples of the raw sewages from various plants were obtained on different week days for jar tests. The laboratory analysis of these samples is also shown in Appendix I.

The results of the jar tests with various chemicals and chemical combinations are shown in Tables 1 to 4. The chemicals utilized in this study were ferric chloride, alum, lime and a variety of anionic, cationic and nonionic polyelectrolytes. The selection of the optimum chemical dosage was based on the reduction in the turbidity and the pH of the flocculated and settled effluent. Waste samples from all the six treatment plants were utilized for investigations with ferric chloride and alum. The chemical dosages investigated ranged from 25 to 200 mg/l for ferric chloride (Table 1) and 75 to 400 mg/l for alum (Table 2). The settled effluent from the jar tests appeared quite clear for turbidities below 20 and 25 JTU for both the chemicals. For a ferric chloride dosage of 150 mg/l or higher all the effluent samples were extremely clear and had turbidity readings below 15 JTU as well as pH values between 6.0 and 6.7. However, for ferric chloride dosages less than 150 mg/l the clarity of the settled effluent varied from one sewage sample to another. Also, in later experiments, when 50 to 800 gallons of sample was used, a ferric chloride dosage of 150 mg/l resulted in effluent turbidities of only 1 to 4 JTU. Therefore, a dosage of 150 mg/l was considered optimum for the chemical treatment of raw sewage with ferric chloride.

Wastewater samples treated with alum indicated that a minimum alum dosage of 200 mg/l was required to bring about any significant reduction in the turbidity (Table 2). The clarity of the settled effluent varied considerably for alum dosages between 200 and 250 mg/l. For alum dosages higher than 250 mg/l the turbidity of the treated effluent was below 17 JTU in most cases and the pH ranged from 6.1 to 6.8. Therefore, an alum dosage between 250 and 300 mg/l was considered optimum. Raw wastewater samples treated with lime (CaO) were visually turbid in most cases and had very high pH values (>9.0). Lime dosages utilized for this investigation spanned over a wide range of 100 to 1000 mg/l (Table 3). The investigations with lime were discontinued early in the study because of its unreliability in producing a visually clear supernatant and the extra cost of pH adjustment involved in reducing the effluent pH (necessary for RO treatment with the cellulose acetate membranes).

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TABLE 1

JAR TEST RESULTS WITH FERRIC CHLORIDE ($FeCl_3$)

$FeCl_3$ Dosage mg/l	Origin of Waste*	No. of Samples Utilized	Effluent pH	Effluent Turbidity JTU
0 (raw waste)	1 to 6	14	6.9-8.1	49->100
25-75	1 to 6	30	6.5-7.2	25
100	1, 4	5	6.6-7.0	20-31
100	2,3,5,6	9	6.3-6.8	13-25
125	4	2	6.6, 7.0	28, 31
125	1,2,3,5,6	12	6.1-6.8	11-21
150	1 to 6	10	6.0-6.7	8-15
175-200	1, 6	4	6.3-6.6	7-11

* Sewage Treatment Plants:
1. Brookfield
2. Jones Island (Milwaukee)
3. Kenosha
4. Puetz Road (South Milwaukee)
5. Racine
6. Waukesha

TABLE 2

JAR TEST RESULTS WITH ALUM ($Al_2(SO_4)_3 \cdot 18H_2O$)

Alum Dosage mg/l	Origin of Waste *	No. of Samples Utilized	Effluent pH	Effluent Turbidity JTU
0 (raw waste)	1 to 6	14	6.9-8.1	49->100
75-150	1 to 6	6	--	>38
200	1 to 6	14	6.5-7.2	20-40
225	1 to 6	12	6.4-6.9	20-28
250	1 to 6	14	6.3-6.9	15-23
275	1 to 6	12	6.2-6.8	8-20
300	1 to 6	12	6.1-6.8	7-17
400	1, 6	2	6.2-6.5	11-12

* Sewage treatment plants :
1. Brookfield
2. Jones Island (Milwaukee)
3. Kenosha
4. Puetz Road (South Milwaukee)
5. Racine
6. Waukesha

TABLE 3

JAR TEST RESULTS WITH LIME (CaO)

Lime Dosage mg/l	Origin of Waste*	No. of Samples Utilized	Effluent pH	Effluent Turbidity JTU
0 (raw sewage)	1, 6	4	7.6, 7.8	>65
100-450	1, 6	10	8.9-9.5	>35
500	1, 6	3	10.2, 9.6	>32
500	6	1	9.1	8
500-1000	1	5	9.0-12.0	>35
500-800	6	3	9.0-11.6	6-8
800-1000	6	2	11.0	18, 40

* Sewage treatment plants:

1. Brookfield
2. Jones Island (Milwaukee
3. Kenosha
4. Puetz Road (South Milwaukee)
5. Racine
6. Waukesha

The results of the jar tests with various polyelectrolytes and chemical combinations are summarized in Table 4. Most polyelectrolytes and their combinations with ferric chloride or alum did not produce any encouraging results. The settled effluent turbidities with logically selected dosages of chemical combinations that might have given some economic advantage compared to the treatment cost with ferric chloride or alum alone were generally higher than 20 JTU. A comparison of the chemical treatment costs in ¢/1000 gallons for various chemicals and dosages along with the unit prices for the chemicals is shown in Table 5. It can be seen that for most optimum chemical dosage combinations with polyelectrolytes the treatment costs are generally higher than those with $FeCl_3$ or alum alone. However, it should be noted here that a combination of ferric chloride and alum did produce a desirably clear effluent. For $FeCl_3$ dosages between 15 and 50 mg/l and alum dosages between 100 and 125 mg/l, the turbidity of the settled effluent ranged between 11 and 25 JTU (Table 4). The effluent pH was between 6.5 and 6.7 and therefore was within the desirable range for RO treatment. Such a combination of ferric chloride and alum may also produce some reduction in the cost of chemical treatment as compared to $FeCl_3$ or alum alone.

Ferric chloride and alum were concluded to be the most suitable chemicals for the pretreatment of raw sewage because of the following advantages:

1. Very clear supernatant
2. Effluent pH between 6.0 and 7.0 (required no pH adjustment for further RO treatment)
3. Good settling characteristics
4. Versatility of these chemicals
5. Low cost of chemical treatment (3.5 to 5.5 ¢/1000 gal)

Reverse Osmosis Evaluations

Raw sewage (screened through mesh No. 8) from the Milwaukee Sewage Treatment Plant was utilized for the RO evaluations. Milwaukee sewage, which can be considered typical to that of any metropolitan area, is a high strength mixture of domestic sewage and industrial wastes, and has an average BOD of approximately 200 mg/l. The reverse osmosis evlauations consisted of utilizing two feed water sources, i.e. settled sewage and chemically treated settled sewage. Raw sewage samples (representing grab samples) from 50 to 1200 gallons were brought to Rex laboratories in a truck in batch loads. A sample after 1 to 2 hour sedimentation in the laboratory constituted the settled sewage, while a sample after flocculation with ferric chloride and 1 to 2 hour sedimentation constituted the chemically treated settled sewage. The old tubular modules (types 300 and 500) were utilized for the flux decline evaluation studies (because of the non-availability of the new modules at that time), while the new modules (Types 310 and 510) were used for the evaluation of the permeate and concentrate quality data.

TABLE 4

JAR TEST RESULTS WITH POLYELECTROLYTES AND OTHER CHEMICAL COMBINATIONS

Range of Chemical Dosages Investigated mg/l	Origin of Waste*	No. of Samples Utilized	Range of Optimum Chemical Dosage mg/l (if any)	Effluent Characteristics with Optimum Chemical Dosage		
				pH	Turbidity JTU	Remarks
Dow A23: 0.15-5.0	1, 6	34	none	>7.0	>28	No clarity achieved
Alum: 150-225 & A23: 0.5-2.0	2, 4	18	175-200 & 0.5-1.0	6.4-7.0	18-28	No exceptional clarity High chemical costs
Alum: 100-200 & C31: 0.5-2.0	2, 4	15	150-200 & 0.5-1.0	6.5-7.0	18-20	No exceptional clarity High chemical costs
$FeCl_3$: 25-75 & A23: 0.25-20	2,3,4,5	24	50-75 & 0.25-1.0	6.6-6.9	22-42	Medium clarity, wide variation in effluent quality
$FeCl_3$: 25-50 C31: 0.5-4.0	2,3,4,5	27	50 & 0.5-2.0	6.8-7.0	11-35	Medium clarity, wide Variation in effluent quality
$FeCl_3$: 25-50 C7: 0.25-1.5	3, 5	12	none	∿7.0	>30	No clarity achieved
$FeCl_3$: 25-50 Herco 822A: 0.25-2.0	3, 5	10	none	∿7.0	>30	No clarity achieved
$FeCl_3$: 25-50 Herco 810C: 0.5-3.0	3, 5	16	none	6.6-7.2	>24	No clarity achieved

TABLE 4 (cont.

JAR TEST RESULTS WITH POLYELECTROLYTES AND OTHER CHEMICAL COMBINATIONS

Range of Chemical Dosages Investigated mg/l	Origin of Waste*	No. of Samples Utilized	Range of Optimum Chemical Dosage mg/l (if any)	Effluent Characteristics with Optimum Chemical Dosage		
				pH	Turbidity JTU	Remarks
$FeCl_3$: 25-50 675A: 0.25-1.0	3, 5	12	none	6.8-7.1	22-44	No clarity achieved
$FeCl_3$: 25-50 905N: 0.5-2.0	3, 5	12	none	6.8-7.0	>35	No clarity achieved
$FeCl_3$: 10-50 Alum: 50-125	3, 5	18	15-50 & 100-125	6.5-6.7	11-25	Good clarity. Economical chem. dosages

* Sewage treatment plants

1. Brookfield
2. Jones Island (Milwaukee)
3. Kenosha
4. Puetz Road (South Milwaukee)
5. Racine
6. Waukesha

TABLE 5

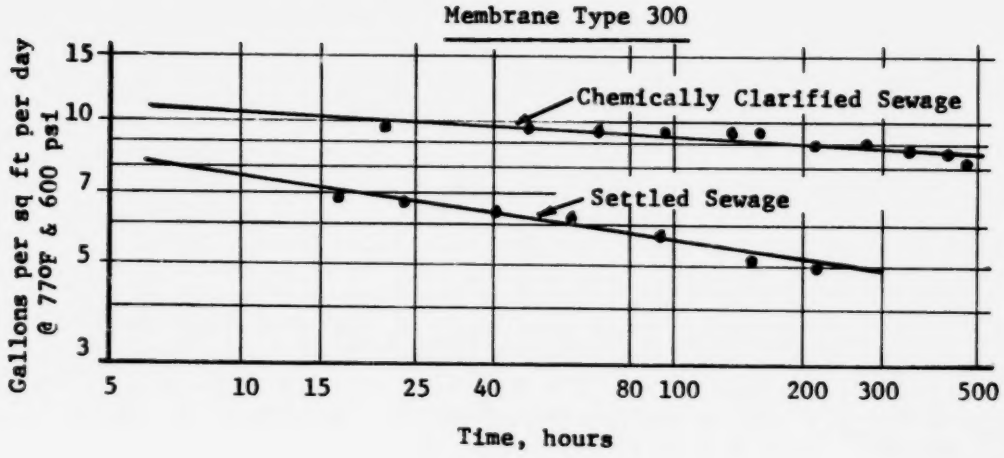
COST OF CHEMICAL TREATMENT

Chemical	$/ton	$/lb	Cost in ¢/1000 gal for Dosages in mg/l Concentrations												
			.25	.50	1.0	10.0	25.0	50.0	75.0	100	150	200	250	300	500
$FeCl_3$	90.0	--	--	--	--	.375	.94	1.88	2.82	3.75	5.64	7.50	--	--	--
Alum	40.0	--	--	--	--	--	.42	.84	1.26	1.68	2.51	3.35	4.2	5.04	--
Lime	16.6	--	--	--	--	--	--	--	--	.65	.98	1.30	1.62	1.94	3.24
A23	--	1.35	.282	.565	1.13	--	--	--	--	--	--	--	--	--	--
C31	--	.38	.08	.16	.32	--	--	--	--	--	--	--	--	--	--
822A	--	1.25	.261	.523	1.04	--	--	--	--	--	--	--	--	--	--
675A	--	1.51	.315	.630	1.26	--	--	--	--	--	--	--	--	--	--
810C	--	1.45	.303	.606	1.21	--	--	---	--	--	--	--	--	--	--
905N	--	1.40	.292	.585	1.17	--	--	--	--	--	--	--	--	--	--
C7	--	1.00	.209	.418	.835	--	--	--	--	--	--	--	--	--	--

Evaluation of Flux Decline Rates

Two experiments were made to evaluate the flux decline characteristics of the tubular RO system for the two feed water sources without any disinfection of the RO feed. The pretreatment for experiment #1 consisted of treating the raw sewage with 150 mg/l ferric chloride followed by one hour sedimentation. The pretreatment for Experiment #2 consisted of 1.5 hours sedimentation and a pH adjustment of the settled sewage effluent with sulfuric acid to a value below 7.0 (required for cellulose acetate membranes). No pH adjustment in experiment #1 was necessary because of the use of $FeCl_3$ which lowered the feed pH between 6.0 and 7.0. Experiment #1 was concluded at the end of 480 hours of test duration while experiment #2 lasted slightly over 200 hours. Both these experiments were made on batch samples by recycling the concentrate and product water streams to the feed water tank. No disinfectants to control bacteria growth or chemical dispersing agents to control precipitation or any kind of flushing procedures were utilized during these test runs. A feed flow rate of 1.3 gpm per module row(3 modules in series) was maintained, which resulted in feed velocities between 1.5 to 2.0 ft/sec. Operating pressures of 600 psi at the inlet and a feed water recovery of approximately 25% were utilized in these experiments.

The variation of the flux rates on a log-log scale is shown in Figure 6 for the two membrane types as well as the feed water type. The lower initial flux rates for the settled sewage experiment compared to those for the chemically treated sewage were due to the sequence of these two experiments, whereby the flux rates had already been reduced in the former experiment. Flux decline slopes for the chemically treated sewage were -0.06 for membrane type 300 and -0.027 for membrane type 500. The corresponding slopes for settled sewage were -0.13 and -0.10. The comparative slopes for these two membrane types, when a nonfouling inorganic solution was utilized, were -0.06 and -0.01 (19). These reference slopes with the inorganic solution are typical of the compaction slopes for the respective membranes. It is clear from Figure 6 that the flux decline rates for the settled sewage are much higher than the chemically treated and settled sewage. The continued steep decline of flux rates in Experiment #2 (settled sewage) indicated significant fouling of the membranes due to the presence of higher amounts of organic material compared to the flux decline rates observed in Experiment #1 (chemically treated sewage) for which the predominant cause of flux decline can be attributed to membrane compaction. It should be noted that some flaky materials were loosened and were observed in the concentrate when the membranes were flushed at the end of the experiment with chemically treated sewage. This indicated some deposition of the organic material on the membranes in Experiment #1 although it was not as significant as in Experiment #2. Also, it may be recognized that the flux decline slopes shown may not be truly representative of the slopes expected in the field for a full scale system because of the utilization of laboratory scale batch



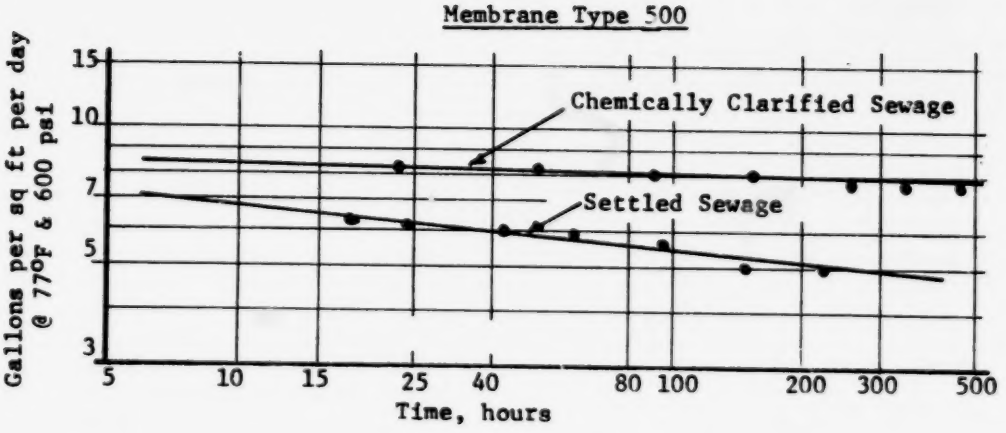


Figure 6

LOGARITHMIC VARIATION OF FLUX RATES

recycling procedures. But the steeper flux decline shown for the settled sewage as compared to the chemically treated sewage is quite representative of the membrane fouling phenomenon. The longer test durations up to 500 hours also demonstrate the effect of the membrane compaction characteristics. However, it is recommendedthat a larger capacity RO system at higher feed water recoveries on a continuous flow stream be utilized for more exact information on flux decline rates.

The looser membranes (Type 300) showed only a two gallon per day per sq ft or 25% higher initial flux rate (10.5 gal/sq ft/day for type 300 and 8.5 gal/sq ft/day for type 500) as compared to tighter membranes (Type 500) for Experiment No. 1. The difference in the flux rates for the two membranes was less than 10% within 500 hours (Experiment No. 1). Similar differences in flux rates were observed for the two membranes in Experiment No. 2. However, it should be noted that the modules utilized in these experiments had already been used earlier for over 3000 hours under various investigations. The difference in flux rates for the two membranes was considerably higher when these membranes were new, (approximately 13.0 gfd for type 300 compared to 9.0 gfd for type 500), but after 3000 hours of operation, the initial flux rates had been reduced to the present levels.

Typical feed and product water quality data and the percent salt rejections for the flux decline evaluation experiments is shown in Table 6. Permeate quality for membrane type 500 was significantly better compared to type 300 as shown by the higher total solid and total organic carbon rejections in both the experiments. Therefore, as a result of the poorer salt rejections and only slightly greater flux rates, the use of membrane type 300 was discontinued. As expected, the percent salt rejections for membrane type 500 remained approximately the same in the two experiments. However, from the permeate quality shown in Table 6, it is clear that a significant amount of total organic carbon (between 15 and 30 mg/l) was passing through the tighter membrane type 500 at a feed water recovery of approximately 25% and this content would increase at higher feed water recoveries. Hence, it was indicated that further treatment of the RO permeate would be warranted in order to utilize this water for domestic purposes.

Additional experiments were continued to evaluate the permeate and the brine water quality obtained via the tight membrance type 500 or 510 at high feed water recoveries of up to 90% with settled and chemically treated sewages. It was decided to utilize a large batch (approximately 1000 gallons) of raw waste for the evaluation of the water quality data and also to produce sufficient RO concentrate that could be further utilized for activated sludge feasibility investigations.

TABLE 6

WATER QUALITY DATA FOR THE FLUX
DECLINE STUDY EXPERIMENTS

Experiment #1	pH	Turbidity JTU	Total Solids mg/l	Total Solids % Rejection	TOC mg/l	TOC % Rejection
Raw Sewage	7.5	100	883	---	177	---
Chemically Treated & Settled (RO Feed)	6.2	9	740	---	72	---
Product Water:						
Membrane Type 500	5.5	<1	65	91	16	78
Membrane Type 300	5.9	<1	215	71	24	67
Experiment #2						
Raw Sewage	7.7	>200	965	---	212	---
Settled Sewage (RO Feed*)	7.7	158	764	---	122	---
Product Water:						
Membrane Type 500	6.0	<1	54	93	27	78
Membrane Type 300	6.6	<1	206	73	39	68

*pH adjusted to 7.0 with sulfuric acid.

Test Conditions: Temperature - 65 to 75°F
Pressure - 600 psi
Feed pH - 6.0 to 7.0
Feed Recovery - Approx. 25%

Experiments with Settled Sewage for Water Quality Evaluation

A sedimentation period of two hours was allowed for the raw waste. A concentration test was performed on the settled effluent whereby the brine was returned to the feed tank while the permeate was continuously wasted. A schematic of the laboratory concentration procedure is shown in Figure 7. Such a concentration system enabled the simulation of the brine water quality at high feed water recovery levels. This system was utilized until a tenfold concentration of the feed water (as shown by the 90% reduction in the original feed water volume) was achieved. The water quality data as obtained from the laboratory analysis of the raw waste, the RO feed after sedimentation and pH adjustment, and the brine at the 90% simulated feed water recovery is shown in Table 7.

From the brine analysis shown in Table 7, it is seen that the concentrations of the various constituents in the brine are significantly less then the expected concentrations (approximately 10 times the feed concentrations). A comparison of this data was then made with the computed water quality data obtained via a computer program available at Rex. This program computes the water quality data at high feed water recoveries from the results obtained at low recoveries through the pilot plant operation. The comparisons shown in Table 8 could only be made for a limited number of constituents for which the product water analyses were available at the lower feed water recovery. It is seen that the computed brine has a significantly higher concentration of various constituents compared to the simulated brine water quality. The reason for such a discrepancy can be attributed to the limitations on the information generated through the concentrate recycling procedure. A schematic comparison of a full size multiple bank RO system designed for a high recovery ratio and the recycling procedure utilized in the laboratory can be made by comparing Figures 5 and 7. Actually, what is happening in the recycling procedure is that a larger amount of dissolved material is passing through the membranes in the permeate than would actually be passed in a full size multiple bank RO system designed for higher feed water recoveries. The reason for such a high amount of material in the permeate of the recycling procedure can be attributed to the low flux rates of the tubular system whereby it took over 70 hours to reduce the feed volume from 975 gallons to 97.5 gallons to achieve the 90% recovery level. Hence, due to the increased salt passage into the permeates, the salt concentrations in the simulated brine become lower than the computed salt concentrations for the corresponding concentrate.

However, it should be kept in mind that the concentrate recycling procedure does have the advantage of producing a reasonably concentrated waste stream in the laboratory that can be utilized for further brine treatment feasibility investigations without incurring the expenses for a full size RO system. Moreover, quite reliable permeate and concentrate quality data at high feed water recoveries can be obtained through

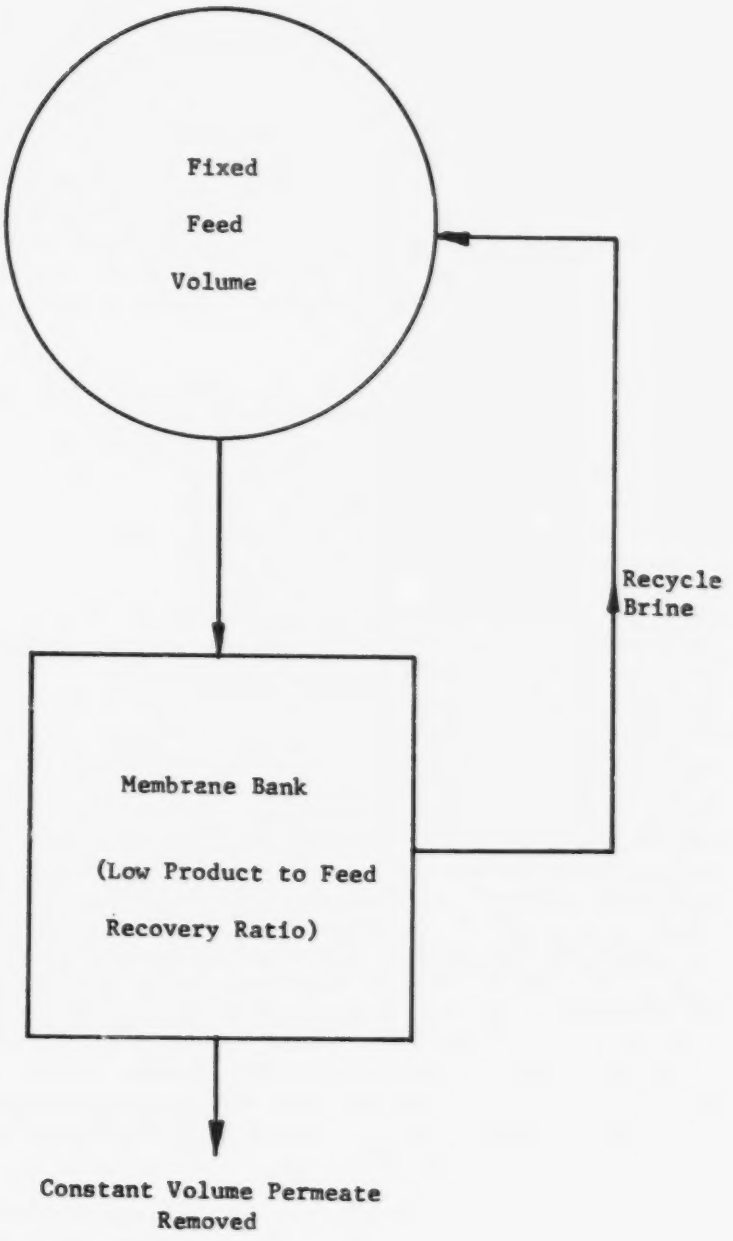


FIGURE 7

LABORATORY CONCENTRATE RECYCLING PROCEDURE

TABLE 7

WATER QUALITY DATA - SETTLED SEWAGE FEED WATER*

Analysis	Raw Sewage	RO Feed**	Concentrate 90 Percent Simulated Feed Water Recovery
pH, units	8.5	6.5	7.2
Total Solids	996	1065	7196
Volatile Total Solids	420	376	1705
Suspended Solids	160	117	308
Volatile Suspended Solids	35	18	235
Total Organic Carbon	196	192	810
Total Inorganic Carbon	46	20	100
Chemical Oxygen Demand	537	507	2260
Total Nitrogen (Kjeldahl)	30.5	27.7	170
Nitrate as N	--	1.85	0.20
Nitrite as N	--	0.75	0
Ammonia as N	--	12.8	7.5
Total PO_4 as P	1.56	1.53	5.55
Ortho PO_4 as P	0.91	1.21	1.93
Total Hardness as $CaCO_3$	255	267	2200
Sulfates	200	340	2600
Chlorides	126	132	975
Total Iron	0.7	--	8.6
Total Alkalinity as $CaCO_3$	275	127	1025
Turbidity JTU	165	130	>500

NOTE: All results in mg/l, except where noted.

*Sample No. 1, RO treatment with tubular membrane type 510

**Supernatant after 2 hour sedimentation and pH adjustment with H_2SO_4.

TABLE 8

COMPARISON OF CONCENTRATE QUALITIES AT 90% FEED WATER RECOVERY*

Analysis	Concentrate Quality Obtained Through the Experimental Simulation	Concentrate Quality Calculated Through The Computer Program
Total Dissolved Solids	6886	8950
Total Organic Carbon	810	1405
Chemical Oxygen Demand	2260	3590

NOTE: All results expressed in mg/l.

*Sample No. 1, RO treatment with tubular membrane type 510.

the computer program mentioned.

Another experiment was made on a second sample of the raw sewage from the Milwaukee Sewage Treatment Plant following two hour sedimentation and pH adjustment. The feed and the product water quality data were obtained at a low feed water recovery of 20 percent. This data was then utilized to predict the permeate quality, overall percent salt rejections and the concentrate quality at a feed water recovery of 91.4% with the help of the computer program. The results of the laboratory analysis as well as the calculated data at higher feed water recovery is shown in Table 9.

The permeate and concentrate water qualities shown in Table 9 can be considered to be typical of the two streams obtained through the reverse osmosis treatment of any high strength domestic waste at high feed water recovery ratios. It can be seen that although the TDS content in the permeate is only 70 mg/l, the BOD_5, the TOC and the COD contents are extremely high at 108, 67 and 182 mg/l, respectively. Also, the overall soluble TOC rejection is of the order of only 50%. This further illustrates the poor organic rejections shown by cellulose acetate membranes (CA) at high recovery ratios.

From the experiments described above it may appear the the physical handling of settled sewage through the tubular RO systems can be done without a significant number of problems, but actually several mechanical problems were encountered during the course of the experiments. It appears that a flow scheme in which the primary effluent is directly utilized for RO treatment, would present a great risk to the life of the mechanical as well as the membrane hardware. The amenability of even the tubular RO system to plugging was demonstrated during the second experiment with the settled sewage. It was found that in spite of the removal of the larger solids, sufficient suspended material in the form of gum, grease and other floating organic material remained in the settled supernatant and had a tendency to conglomerate and block the flow through the tubular system. In one instance of a plugged module, it was found that the fine suspended organic material had conglomerated with hair in the presence of grease to plug the tubular system. Moreover, in the new Havens tubular system, the solids handling capacity has become further limited because of the introduction of the turbulence promotor rods provided for minimizing the concentration polarization effects. Therefore, it is considered essential that prior additional treatment over and above plain sedimentation of the raw sewage will be needed before RO treatment.

Experiments with Chemically Treated Sewage

A ferric chloride dosage of 150 mg/l was utilized for the chemical flocculation of the raw waste and following a two hour sedimentation period, the settled effluent was treated by reverse osmosis. Since the main objective of the experiments was to evaluate the water quality

TABLE 9

WATER QUALITY DATA - SETTLED SEWAGE FEED WATER [1]

Analysis	Laboratory Analysis Results			Calculated Data Through Computer Program @ 91.4% Feed Recovery		
	Raw Sewage [2]	RO Feed [3]	Product Water @ 20% Recovery	Product Water	% Rejection by Membrane	Concentrate Quality
pH, units	8.2	6.5	5.9	--	--	--
Total Solids	1912	1345	30	70	94.8	--
Total Volatile Solids	963	458	14	36	92.3	--
Suspended Solids	1043	321	0	0	100	--
Volatile Suspended Solids	684	273	0	0	100	--
Total Dissolved Solids	869	1024	30	70	93.1	11175
BOD_5	525	308	53	108	65.0	2439
BOD_{21}	--	444	74	151	65.9	3560
COD	1202	740	85	182.6	75.3	6671
TOC	508	300	31	67	77.5	2776
TIC	76	24	3	6.4	73.4	212
Soluble TOC	--	110	29	54	50.9	706
Soluble TIC	--	20	3	6.2	68.8	166
Total Hardness as $CaCO_3$	--	335	10	23	93.1	3651
Calcium as $CaCO_3$	--	260	5	12	95.5	2901
Magnesium as $CaCO_3$	--	75	5	11	85.0	753
Organic Nitrogen as N	--	18.7	0	0	100	218
Ammonia as N	--	21	1.1	2.5	88.0	218
Total Phosphate as P	--	10.3	0.12	0.3	97.0	117
Ortho Phosphate as P	--	3.2	0.01	0.02	99.0	36
Sulfate	--	250	2.5	6	97.6	2847
Chloride	--	230	11	25	89.0	2409
Total Iron	--	0.9	0.16	0.3	64.0	7
Ferrous Iron	--	0.4	0.1	0.2	52.8	2.6
Alkalinity as $CaCO_3$	360	142	12	26.6	81.2	1370
Total Coliforms, #/ml	--	1.2×10^5	0	0	100	--

1. Sample No. 2; RO treatment with tubular membrane type 510. 2. Screened through mesh No. 8.
3. Supernatant after 2 hours sedimentation & pH adjustment with sulfuric acid. 4. All results in mg/l.

data at high feed water recoveries and since considerable difficulties had been experienced earlier in obtaining a representative brine sample at high recoveries with the tubular system in batch experiments, an alternate method of achieving the same objective was adopted. It was indicated through some cursory experiments that recently developed high flux cellulose acetate membranes marketed by Gulf Environmental Systems with the spiral wound configuration had over 300% greater flux rates with comparable rejections shown by the tubular membrane type 510. Also, the clarity of the chemically treated sewage was found to be suitable as feed to the spiral wound modules for short term feed concentration tests. With the switch over to the spiral wound membrane, it took only six hours to concentrate 800 gallons of chemically treated sewage compared to over 50 hours for corresponding amounts with the tubular system. Samples of raw, chemically treated sewage and the RO product water at a feed water recovery of 35% were analyzed in the laboratory. The results were also subjected to a computer program discussed earlier and the product and brine water quality at 92% feed water recovery level was calculated. The results of the laboratory analyses as well as the calculated data of the higher feed water recovery are shown in Table 10. From the brine qualities shown in this table, it is clear that, because of the short duration of the concentration experiment the computer calculation and laboratory analysis results match quite closely (within 10% compared to approximately 25% for TDS in Table 8 for the tubular system).

The product water at the high feed water recovery of 92% was again found to be of extremely good quality as far as inorganic content was concerned. The permeate was calculated to have a TDS concentration of 140 mg/l, which is well below the recommended public health standard for dissolved solids (500 mg/l). However, a high amount of organic material was again found to be permeating through the CA membranes as shown by the calculated BOD, COD and TOC values in Table 10. At this point in time, an interesting observation was made relative to the brine and permeate qualities at high feed water recoveries.

A composite sample of product water was obtained at the 92% recovery level from the batch recycling procedure for permeate investigation purposes. It was found to exhibit a TOC value of only 36 mg/l as opposed to the calculated TOC value of 51 mg/l (Table 10) at corresponding recoveries. Also, the calculated brine TOC of 525 mg/l was considerably less than the analyzed TOC value of 710 mg/l at 92% recovery. When a mass balance on the TOC values was made, the laboratory-analyzed values checked out within 10% accuracy. This meant that some specific organic compounds were passing through the CA membranes and once these had passed from the fixed volume of feed utilized in a batch type experiment, further concentration of the feed would not be correctly reflected in the organic quality of the permeate or brine through the computer program. The above conclusion was further supported later in the course of the permeate investigations when it was shown that approximately 70% of the organic material permeating through the membrane was ethanol for the Milwaukee sewage utilized. However, for purposes of the

TABLE 10

WATER QUALITY DATA - CHEMICALLY TREATED & SETTLED SEWAGE FEED WATER[1]

Analysis	Laboratory Analysis Results				Calculated Data Through Computer Program @ 92% Feed Recovery		
	Raw Sewage[2]	RO Feed[3]	Product Water @ 35% Recovery	Concentrate 92% Recovery	Product Water	Percent Rejection by Membrane	Concentrate Quality
pH, units	8.6	6.6	5.6	7.5	--	--	--
Total Solids	1068	959	67	--	140	85.4	--
Total Volatile Solids	364	286	22	2470	45	84.3	2900
Suspended Solids	144	3	0	--	0	100	--
Volatile Suspended Solids	106	3	0	--	0	100	--
Total Dissolved Solids	924	956	67	9370	140	85.4	10000
BOD_7	262	177	66	1000	99	44.0	920
Soluble BOD_7	--	146	66	770	99	32.2	650
BOD_{21}	403	239	88	1060	142	40.6	1250
COD	472	295	131	--	200	32.2	--
Soluble COD	--	291	131	1760	200	31.3	1280
TOC	173	91	31	710	51	44.0	525
TIC	61	21	1	245	2	90.5	230
Soluble TOC	--	90	31	574	51	43.3	515
Soluble TIC	--	20	1	226	2	90.0	220

1. RO treatment with high flux spiral-wound membranes.
2. Screened through mesh No. 8
3. Supernatant after flocculation with 150 mg/l $FeCl_3$ and 2 hours sedimentation.
4. All results in mg/l except where noted. Operating pressure - 600 psi

TABLE 10 (Cont.)

WATER QUALITY DATA - CHEMICALLY TREATED & SETTLED SEWAGE FEED WATER[1]

	Laboratory Analysis Results				Calculated Data Through Computer Program @ 92% Feed Recovery		
Analysis	Raw [illegible][2]	RO Feed[3]	Product Water @ 35% Recovery	Concentrate 92% Recovery	Product Water	Percent Rejection by Membrane	Concentrate Quality
Organic Nitrogen as N	10.2	7.0	0.3	72	0.6	91.4	79
Ammonia as N	13.6	14.9	8.1	68	11.5	22.8	54
Nitrate as N	2.23	2.25	0.77	1.7	1.3	42.2	16.2
Nitrite as N	[illegible]	0.05	0.03	0.6	0.04	20.0	0.2
Total Phosphate as P	[illegible]	0.17	0.06	0.6	0.09	47.1	0.9
Ortho Phosphate as P	5.6	<0.05	<0.05	<0.05	--	--	<0.1
Total Hardness as $CaCO_3$	328	318	4	3590	8	97.5	3650
Calcium as $CaCO_3$	260	250	2	2550	4	98.4	2800
Magnesium as $CaCO_3$	68	68	2	1040	4	94.1	850
Sulfate	--	118	1	1240	2	98.3	1440
Chloride	--	334	27	3050	55	83.5	3400
Total Iron	1.5	1.1	<0.1	--	0.2	81.8	11
Total Alkalinity as $CaCO_3$	285	100	4	1250	8.5	91.5	1125
Phenols	0.5	0.5	0.5	--	--	--	--

1. RO treatment with high flux spiral-wound membranes.
2. Screened through mesh No. 8
3. Supernatant after flocculation with 150 mg/l $FeCl_3$ and 2 hours sedimentation.
4. All results in mg/l except where noted. Operating pressure - 600 psi.

evaluation of the water quality, the calculated data through the computer program can be considered more representative for the inorganic ions while the analyzed brine values can be considered typical of the organic content.

Overall Evaluation of the Membrane Rejection Characteristics

The tighter membrane Type 510, exhibited a consistent rejection pattern for the various inorganic and organic species. In general, the percent rejection of the dissolved inorganic matter was significantly better than that of the dissolved organic material. Among the various inorganic ions, the rejection of the divalent ions such as calcium, magnesium, and sulfates was considerably better than the monovalent ions such as chlorides and ammonium. Following is a summary of the typical percent rejections expected for various constituents in domestic sewage when tighter membrane type 510 is utilized at a feed water recovery level of approximately 92%.

Total Dissolved Solids	93%
Total Volatile Solids	92%
Total Hardness	93%
Soluble TOC	40-50%
Soluble TIC	68%
Organic Nitrogen	100%
Ammonia Nitrogen	88%
Phosphates	98%
Chlorides	89%
Sulfates	97%
Alkalinity	81%
Total Coliforms	100%

The percent rejections for the high flux spiral wound membranes(utilized for obtaining the RO concentrate in a shorter time) were either similar or slightly lower for most inorganic and organic constituents at corresponding recovery levels. However, a significant difference in rejection characteristics was shown for ammonia nitrogen. The percent rejection for ammonia nitrogen was found to be only 25% at 90% recovery level by the high flux spiral wound membrance as compared to 88% for the tight tubular membranes.

Activated Sludge Feasibility Results

Separate experiments were conducted on the RO concentrates from the settled sewage and the chemically clarified sewage for the evaluation of the biological oxidation of these concentrates. Since it had already been indicated that prior chemical clarification of the raw sewage would be necessary even when tubular RO systems are utilized, main emphasis of evaluation was shifted toward RO concentrates from chemically clarified sewage. The discussion of the results of the bio-treatment of the settled sewage concentrate along with a complete

record of the biological oxidation data are presented in Appendix II.

Reverse Osmosis concentrate of the chemically treated sewage obtained at a feed water recovery of 92% was subjected to biological oxidation. A sample of the RO concentrate was subjected to atomic absorption analysis for measuring any metallic ion concentration that might be toxic to activated sludge biota. The result of this analysis is shown in Table 11. It can be seen from this table that there are no significant metallic ion concentrations in the RO concentrate except zinc and silica which were found to be 6.6 and 72.3 mg/l, respectively. The return sludge from the Milwaukee sewage treatment plant was found to be suitable for system start-up and no acclimitization of the A.S. biota was needed. Also, subsequent biological oxidation tests made it clear that there were no adverse effects of zinc, silica or any other ion buildups that might be toxic to activated sludge biota.

Batch kinetic experimental procedures were employed for A.S. feasibility investigation. Initially the pilot units were operated in the range of 3400 to 10,000 mg/l MLSS levels. Aeration times up to 24 hours were utilized. It was found that although biological oxidation of the organic matter was occuring at a rapid rate, the settling properties of the activated sludge for mixed liquor solids levels at 7000 and 10,000 mg/l were extremely poor. Therefore, the mixed liquor solids levels were readjusted in the range of 1500 to 6000 mg/l by dilution for further experiments. The results of the biological treatment efficiencies are shown in Figure 8. The biological oxidation of the organics was measured in terms of the total organic removals in the filtered mixed liquor samples at various aeration time intervals and MLSS levels. By plotting the percent soluble TOC remaining against the product of mixed liquor suspended solids (Sa) in mg/l and time of aeration (t) in hours, the effect of various MLSS and aeration times is eliminated for design purposes. Thus, if 90% soluble TOC removal is achieved at a Sa x t value of 20,000 mg/l hrs., several design combinations can be obtained, e.g. at a design MLSS level of 5000 mg/l, the required design aeration time will be 4 hours while the corresponding time will be 5 hours at a MLSS level of 4000 mg/l. The curves in Figure 8 are shown for two sets of data. It is clear from these curves that the biological treatment efficiency of the data taken between 3800 and 6000 mg/l MLSS was greater than the efficiency for MLSS levels below 4000 mg/l. Therefore, the optimum mixed liquor suspended solids levels may lie between 4000 and 6000 mg/l if the sludge separation characteristics are found to be good. The highest soluble TOC removals achieved in the optimum MLSS range were found to be of the order of 90 to 92%. In most cases, soluble TOC removals of the order of 90% were achieved in 4 to 10 hours aeration time depending upon the suspended solids level maintained in the aeration chamber. There was no significant increase in the percent soluble TOC removals beyond a MLSS x Time value of 20,000 mg/l/hr and hence this value is recommended for design purposes.

An important dependent parameter measured in the biological oxidation

TABLE 11

RESULTS OF ATOMIC ABSORPTION ANALYSIS ON RO CONCENTRATE

Analysis	Ion Concentration, mg/l
Chromium	0.0
Cadmium	0.0
Nickel	0.8
Copper	0.1
Lead	0.0
Zinc	6.6
Arsenic	0.0
Silver	0.0
Aluminum	0.02
Silicon (SiO_2)	72.3
Cyanide	0.0

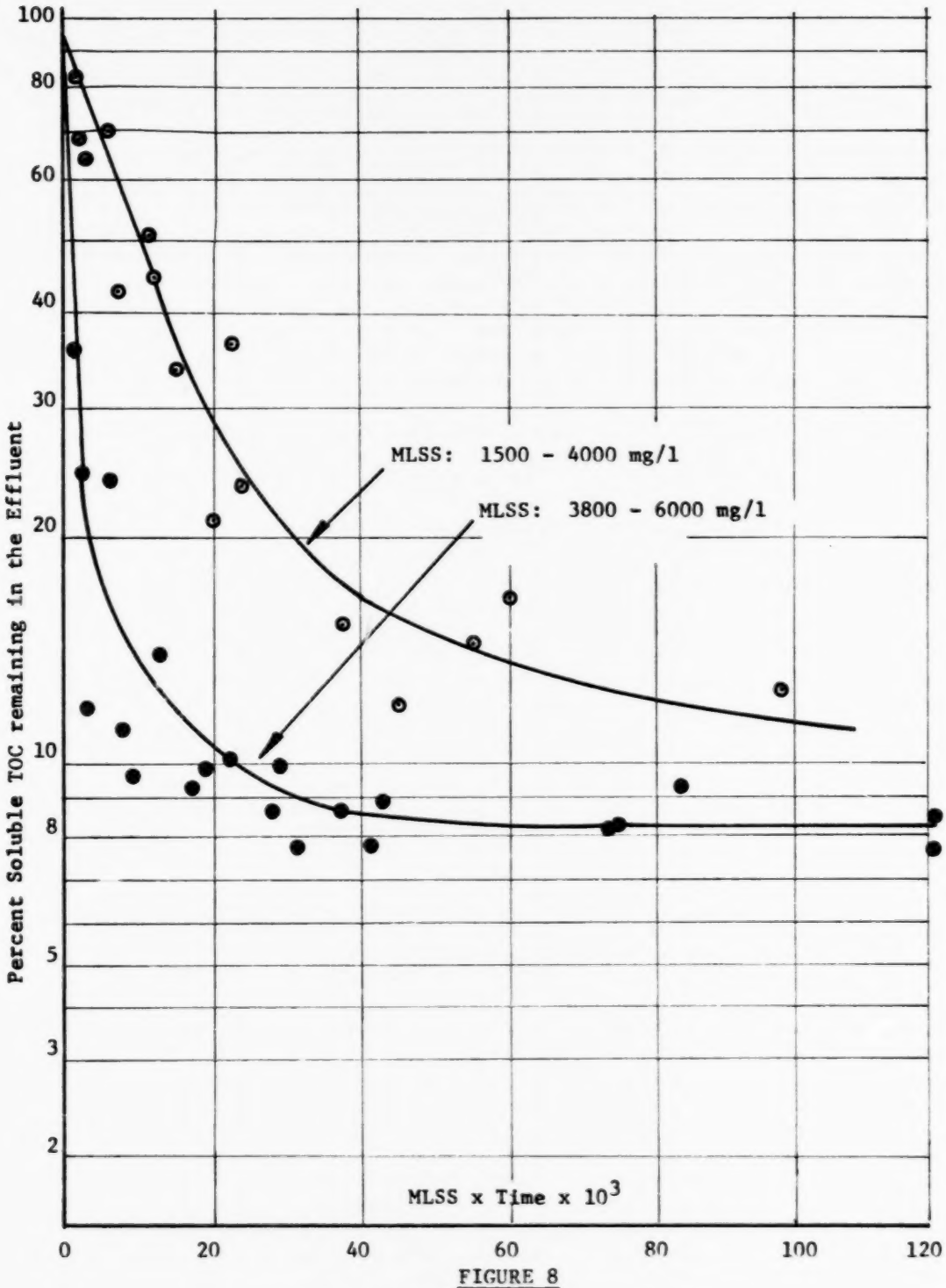


FIGURE 8

BIOLOGICAL TREATMENT EFFICIENCY CURVES

tests was oxygen uptake rate. These rates were measured manually with a dissolved oxygen meter by removing a sample from the pilot unit, measuring the uptake rate and then returning the sample to the unit. The results of the oxygen uptake rate measurements at the high and low mixed liquor suspended solid levels are shown in Figure 9. As expected, the O_2 uptake rate increased markedly immediately after feeding but stabilized to a sustainable average rate within 2 to 5 hours. These rates are indicated by the flat portion of the curve. As food became scarce, the rate fell off gradually until the next feeding. The sustainable oxygen uptake rates at various mixed liquor levels are shown in Table 12. An average uptake rate in the range of 30 to 40 mg/l/hr can be used for design purposes and these should be easily attainable with existing aeration equipment.

As discussed earlier, the solids liquid separation step imposed the limiting restraint towards the maximum level of mixed liquor solids that could be utilized. It was found that the settling velocities at 7000 and 10,000 mg/l solid levels were extremely low at 0.35 and 0.13 ft per hour, respectively as compared to the generally acceptable settling velocity of 4 ft/hour. Settling velocities greater than 5 ft/hour were achieved in most cases at MLSS levels below 6000 mg/l. The variation of the settling velocities with mixed liquor suspended solids is shown in Figure 10. The settling velocities were found to vary widely for specific MLSS levels, but a trend of decreasing settling velocities with increasing mixed liquor solids is quite clearly shown in this figure. Typical settling curves at various mixed liquor solid levels are also shown in Figure 11. It can be noted here that the settling velocity decreased as the concentration of the mixed liquor solids increased. This effect has also been documented elsewhere (20). The SVI index was generally good and ranged between 23 and 102 for the recommended mixed liquor solids range (below 6000 mg/l).

The loading rates in terms of #BOD/#MLVSS were in the range of 0.25 to 0.4. Higher loading rates could not be evaluated within the scope of these bench scale investigations because of the limitation on the amount of RO concentrate available for feeding purposes. The limitation on the availability of the RO concentrate also imposed a restraint on the evaluation of the expected sludge volume production. The data available in this respect was found to be extremely erratic and no definite conclusions could be drawn. Therefore, it is recommended that higher loading rates as well as sludge production be evaluated in the future based on the results of this investigation.

The settled effluent after biological oxidation had a TOC value in the range of 60 to 150 mg/l and a suspended solids concentration in the range of 100 to 150 mg/l. The poorer effluent quality shown during these bench scale investigations may have been a result of overaeration of the mixed liquor in the aeration chambers, since no control was

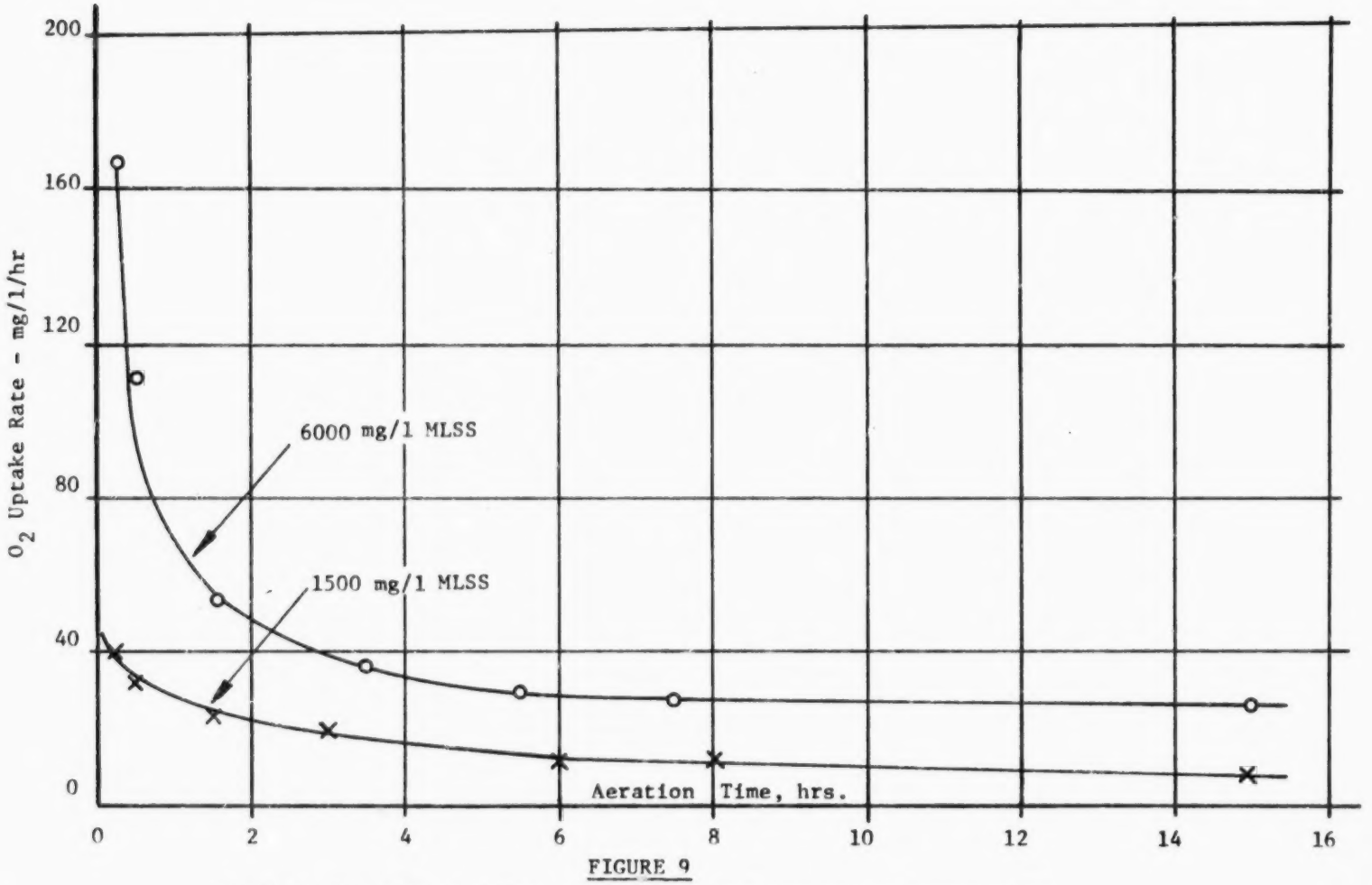


FIGURE 9

OXYGEN UPTAKE RATE CURVE - CHEMICALLY TREATED SEWAGE CONCENTRATE

TABLE 12

BIOLOGICAL OXIDATION DATA
CHEMICALLY TREATED SEWAGE CONCENTRATE[1]

MLSS mg/l	MLVSS mg/l	pH	% TOC Removal Per 24 hr aeration	Effluent S.S.[2] mg/l	Average Sustainable O_2 Uptake Rate mg/l/hr
5850	3450	8.0	91.5	103	30
5000	2900	8.0	92.5	135	36
3800	2000	8.0	91.0	135	27
4000	--	8.1	87.2	---	62
2500	--	8.1	84.7	---	40
1500	--	8.2	71.5	---	19

1 TOC of RO concentrate: 830 and 810 mg/l for two samples
2 After 24 hour aeration and one hour settling

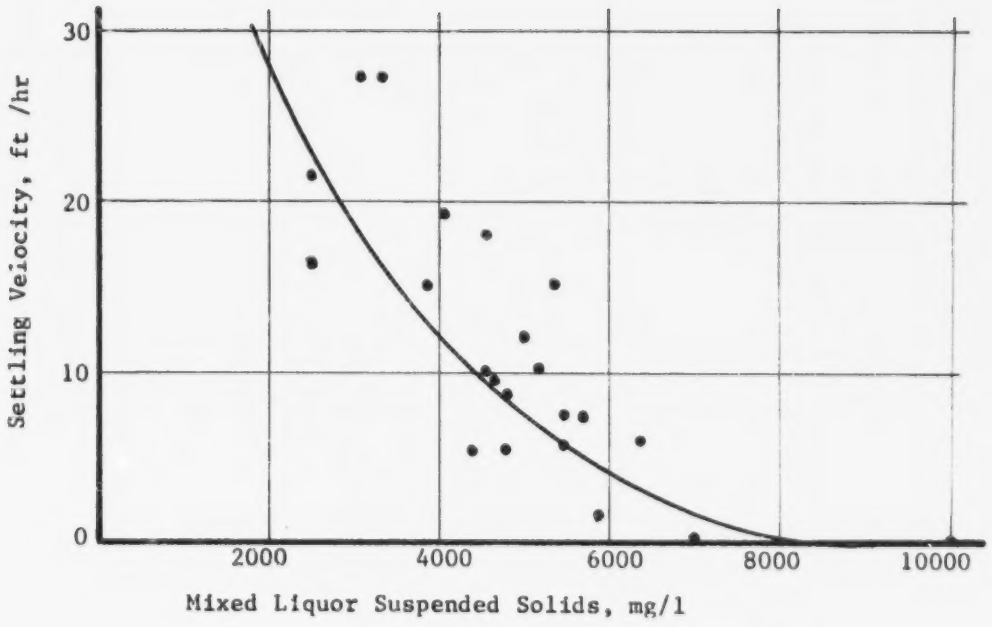


FIGURE 10

VARIATION OF SETTLING VELOCITY WITH MIXED LIQUOR SUSPENDED SOLIDS

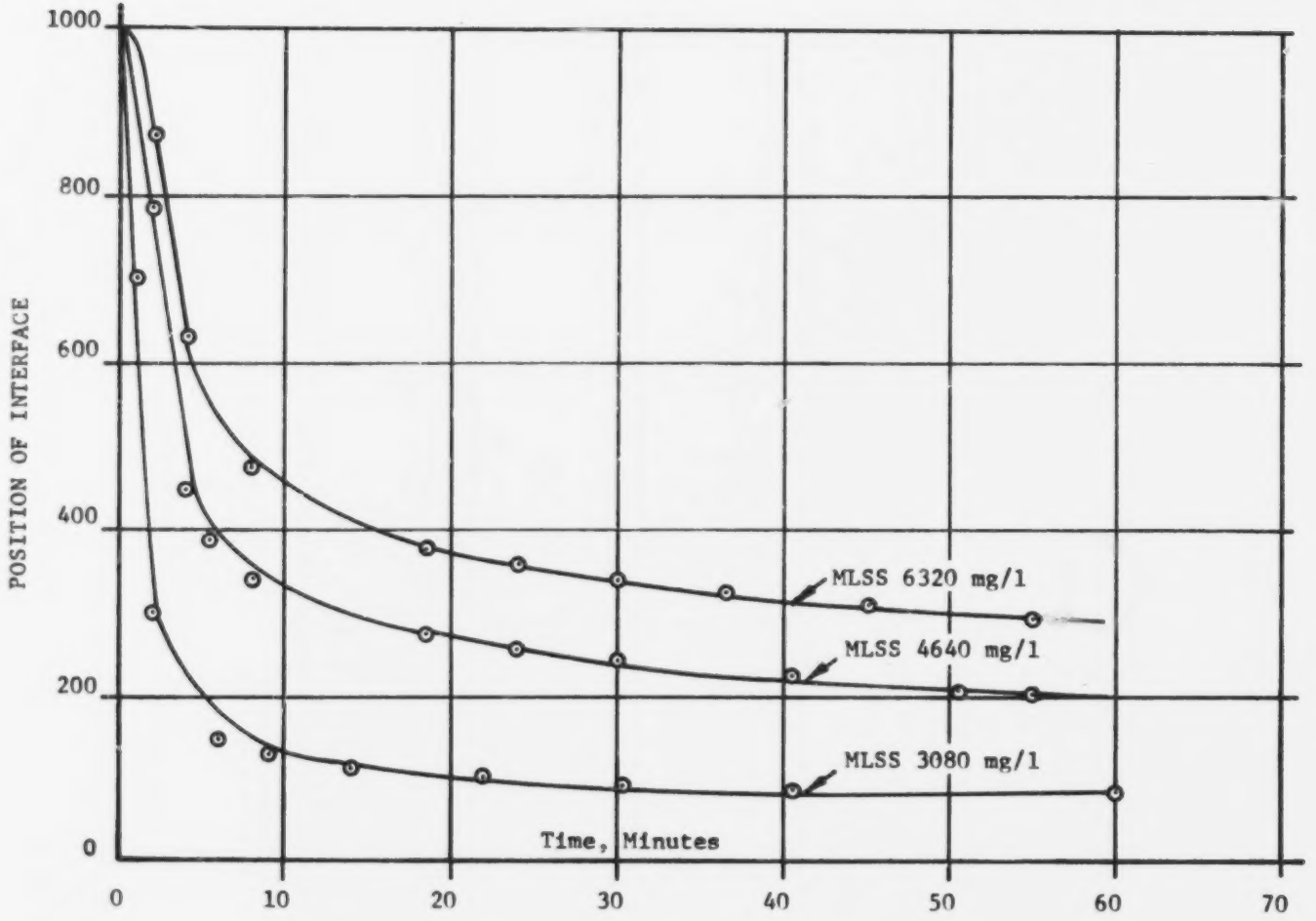


FIGURE 11

TYPICAL SETTLING CURVES FOR RO CONCENTRATE - CHEMICALLY TREATED SEWAGE

exercised on the amount of air being supplied to the aeration units as long as sufficient dissolved oxygen was exhibited in the mixed liquor. The high TOC values of the settled effluent may also have been a result of the increase in the bio-resistant fraction of the sewage due to tenfold concentration. It is expected, however, that the suspended solids removal in the settled effluent will improve considerably for a larger size plant as compared to the pilot unit test results. Also, the TOC values of the settled effluent can be expected to reduce significantly for lower strength domestic sewages. It may also be possible to reduce the organic quality of the biologically treated RO concentrate by undergoing a second biological oxidation in series in an aerated lagoon. This concept could not be evaluated within the scope of this study but such evaluations are recommended for future studies. The TDS content of the settled effluent ranged between 6000 to 7000 mg/l as expected. However, the ammonia nitrogen concentration in the treated effluent was found to be quite high at 87 mg/l. This indicates that if these effluents are to be discharged to streams, stripping of ammonia nitrogen will be necessary even though the organic quality may meet the effluent discharge standards.

Permeate Investigation Results

The objective of this phase of work was to identify any major organic compounds that could pass through the CA membranes. A series of gas/liquid chromatography tests were performed to accomplish this objective. A detailed description of the methods and procedures employed, sample preparation techniques, chromatograms of various samples and the quantitative analysis results are presented in Appendix III. Only the highlights of this work will be discussed in this section.

A typical chromatogram, representative of the product samples from the reverse osmosis tests on Milwaukee Sewage is shown in Figure 12. It consisted generally of four peaks A, B, C and D of which peak B was the largest. The compounds whose peaks did not match peaks A, B, C or D because of the difference in their elution times and were therefore concluded to be not responsible for these peaks were as follows:

Formic acid, acetic acid
Methylamine, ethylamine
Diethylamine
Triethylamine
Formamide
Ethyl acetate
1-propanol, 2-propanol
Phenol

However, it was found that the largest peak B was matched by ethanol (C_2H_5OH) in all tests. Hence, the largest peak was identified as ethanol. Quantitative analysis (by graphical measurement of the area

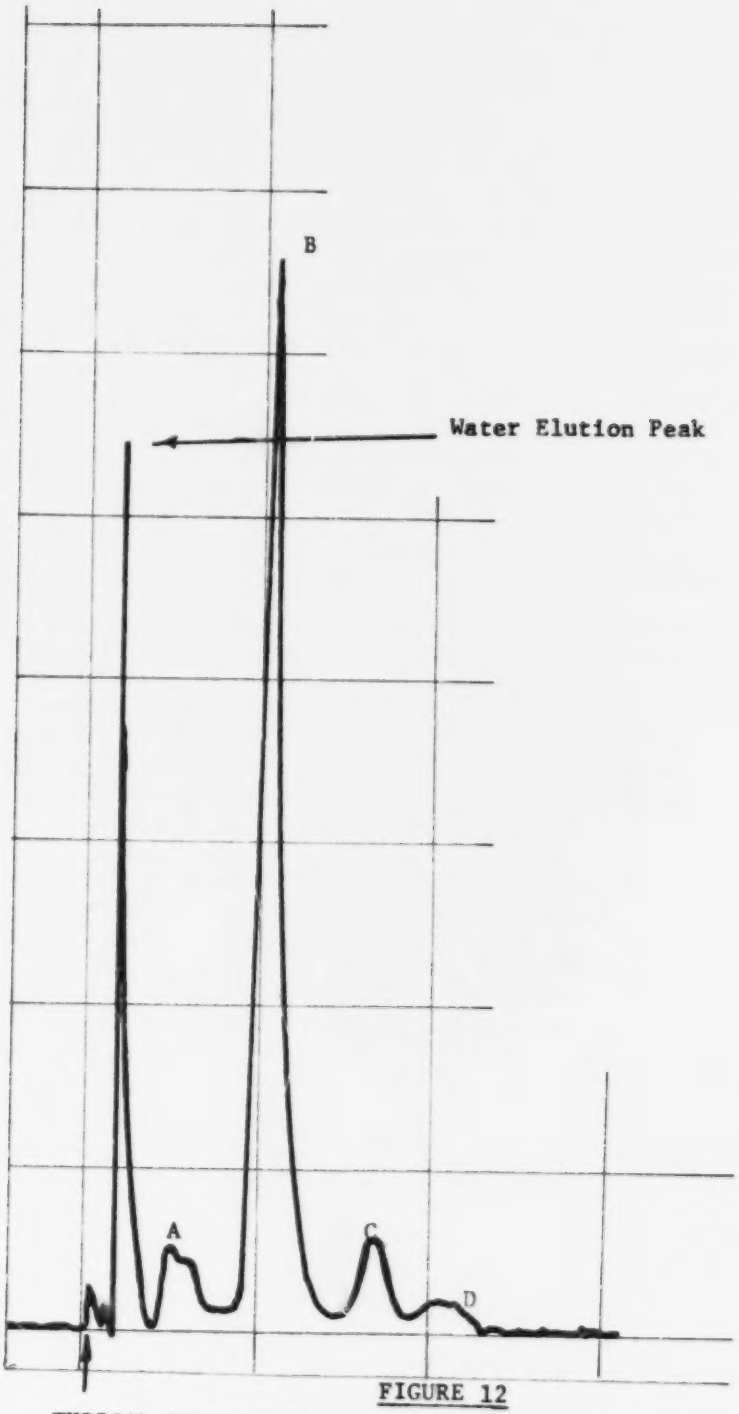


FIGURE 12

TYPICAL CHROMATOGRAM FOR RO SAMPLES OF MILWAUKEE SEWAGE

under the chromatogram peaks) of these peaks indicated that the ethanol content (peak B) was of the order of 70% of the total TOC for most permeate samples. The concentration of the compounds producing the other peaks was indicated to be very small (of the order of 2.0 mg/l or less). Thus, it would appear that the major portion of the organics in the permeate were represented by peak B or ethanol for the Milwaukee sewage.

Chromatograms were also run on raw sewage and other samples to answer some questions concerning the origin and occurrence of the apparent ethanol peak in the permeates. These questions were raised in light of the possibility that the presence of ethanol in Milwaukee sewage may have been a result of Milwaukee's large brewing industry. Peaks A, B, C and D were found in the Milwaukee raw sewage samples. As expected, the portion of the TOC attributable to peak B (ethanol) was small for the raw sewage sample, but the ethanol peak could be distinctly identified. When chromatograms on the raw sewage samples from other nearby cities of Kenosha and Racine were run, no significant amount of peak B could be identified. Therefore, it was concluded that the high concentration of ethanol was peculiar to Milwaukee sewage because of its brewing industry. Also, it was noticed that various other peaks representing other unidentifiable low molecular weight organics were either smaller or nonexistent in the raw sewage samples from other cities compared to Milwaukee sewage. This necessitated the reverse osmosis testing of a sewage sample from a city that did not have a brewing industry.

Therefore, a raw sewage sample from the City of Racine, Wisconsin was subjected to RO evaluations after chemical clarification. The results of these tests are shown in Table 13. It was found that the percent rejection of soluble organic carbon was only 77% at a feed water recovery of 45%. When these results were projected to the 90% recovery level, the soluble organic carbon rejection was calculated to be only 60%. The ethanol content of the feed and permeate was less than 1 mg/l as TOC and yet the soluble organic carbon rejections were not significantly better than for Milwaukee sewage which had contained much larger concentrations of ethanol. This indicates that there is no single predominant organic compound common to various sewages which is responsible for the poor separation performance of the cellulose acetate membranes for soluble organic material. A variety of organics seem to pass through these membranes in very small concentrations and the nature of these compounds also seem to vary over a wide range in various sewages. Identification of all the individual species was beyond the scope of this project, but further investigations on various sewages are recommended to confirm the finds on the Milwaukee and Racine sewages.

Cursory activated carbon treatment tests were also conducted on the RO permeate of the Milwaukee sewage to study the post treatability of the product water towards making it of potable quality. The results

TABLE 13

WATER QUALITY DATA FOR RACINE SEWAGE

Analysis	Feed Quality, mg/l	Permeate Quality, mg/l 45% Recovery	Permeate Quality, mg/l 90% Recovery
Total Dissolved Solids	717	32	61
Soluble Organic Carbon	39	9	15.6
Ethanol as C	<1.0	<1.0	--

*Calculated through a computer program from the laboratory analysis results at 45% recovery level.

indicated that the Milwaukee sewage RO permeate is not amenable to activated carbon treatment as shown by carbon isotherm tests (Table 14, Figure 13). Only 25% of the product water TOC was adsorbed at a Carbon/TOC ratio of 12. This indicated very poor efficiency of carbon utilization which seems to be the result of the poor adsorption affinity of high concentrations of ethanol in the RO permeate. However, this is peculiar to Milwaukee sewage only and has been shown before in an earlier study (21). The other Milwaukee area sewages could, however, be efficiently treated with activated carbon. Therefore, it is expected that the post treatment of RO permeates would be feasible with activated carbon for other sewages not containing ethanol.

TABLE 14

CARBON ADSORPTION ISOTHERM TEST DATA
(MILWAUKEE SEWAGE RO PERMEATE)

Carbon Dose mg/l	TOC of Permeate mg/l	mg TOC Adsorbed / mg Carbon Used	Adsorption Capacity mg TOC/mg Carbon
0	26	--	0.12
125	22	0.032	
250	21	0.020	
500	20	0.012	
1250	19	0.0056	
2500	18.5*	0.0032	

Contact time: 24 hours

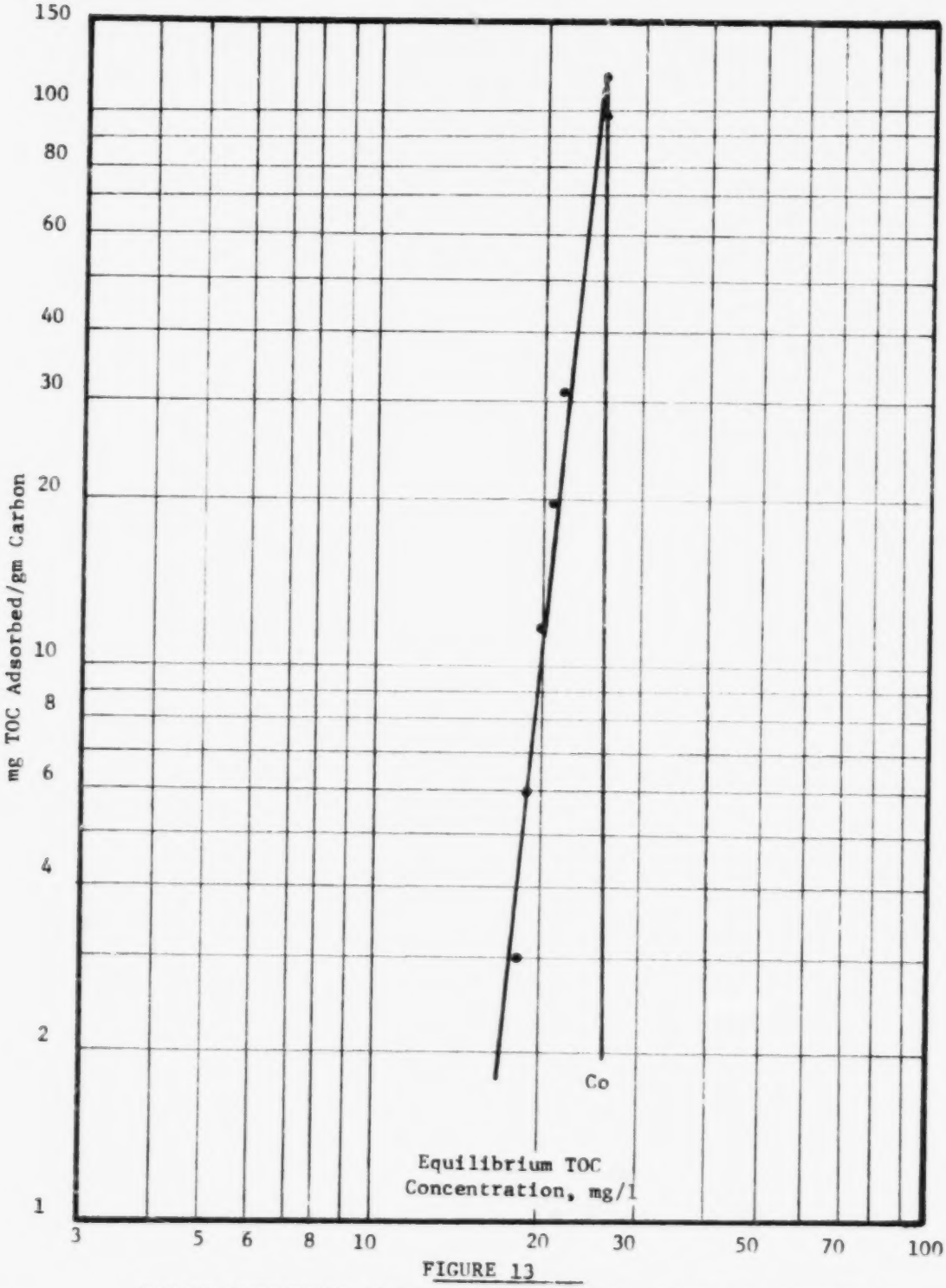


FIGURE 13

CARBON ADSORPTION ISOTHERM FOR MILWAUKEE SEWAGE RO PERMEATE

SECTION VII

APPLICABILITY OF REVERSE OSMOSIS IN THE RENOVATION OF WASTEWATER

This study has made it possible to outline the role of reverse osmosis in the reclamation of wastewaters. It has clearly demonstrated that suitable pretreatment of the raw sewage will be required prior to the RO treatment even when the tubular configuration is utilized. This would be necessary for protecting the mechanical hardware as well as the RO membranes. Also, it was shown that the product waters from the RO treatment were of excellent quality as far as inorganic constituents were concerned but would have to be followed up by some form of post treatment for the removal of the permeating organics to render these waters of potable quality. Since the technical feasibility of utilizing the RO process for the treatment of pretreated domestic waste waters has been proven, the other most important factors affecting the utility of this process in the waste reclamation area are:

1. The need to demineralize wastewater.

2. The economic attractiveness of the reverse osmosis process compared to competing processes.

3. The potential of using reverse osmosis as a pollution control device with discharge to a receiving stream.

The need for demineralization of the waste water has often been emphasized in recent literature (2,3,4,5,9). Moreover, the fact that the dissolved solids content of domestic wastewaters ranges from 500 to 1500 mg/l and the USPHS standards call for a maximum TDS content of 500 mg/l for potable water indicates that the removal of dissolved solids from the wastewaters would be essential in its renovation towards potable use. Furthermore, each domestic use of water supply adds from 300 to 800 mg/l of TDS to the original dissolved solids content of the fresh water. With the impending legislation being sought in several states towards limiting the TDS content of the effluent discharges, it is imperative that the demineralization of the wastewaters be required in the future.

Thus, with the establishment of the need for demineralization, the following treatment scheme utilizing reverse osmosis was developed that would not only provide potable quality water at economically attractive costs for domestic wastewaters but also would reduce pollution to discharging streams:

Proposed Treatment Scheme

Figure 14 shows a schematic of the recommended flow scheme comprised of various treatment processes. This scheme is designed for a medium strength domestic waste having a TOC content of approximately 100 mg/l and TDS concentration of approximately 800 mg/l. The schematic layout

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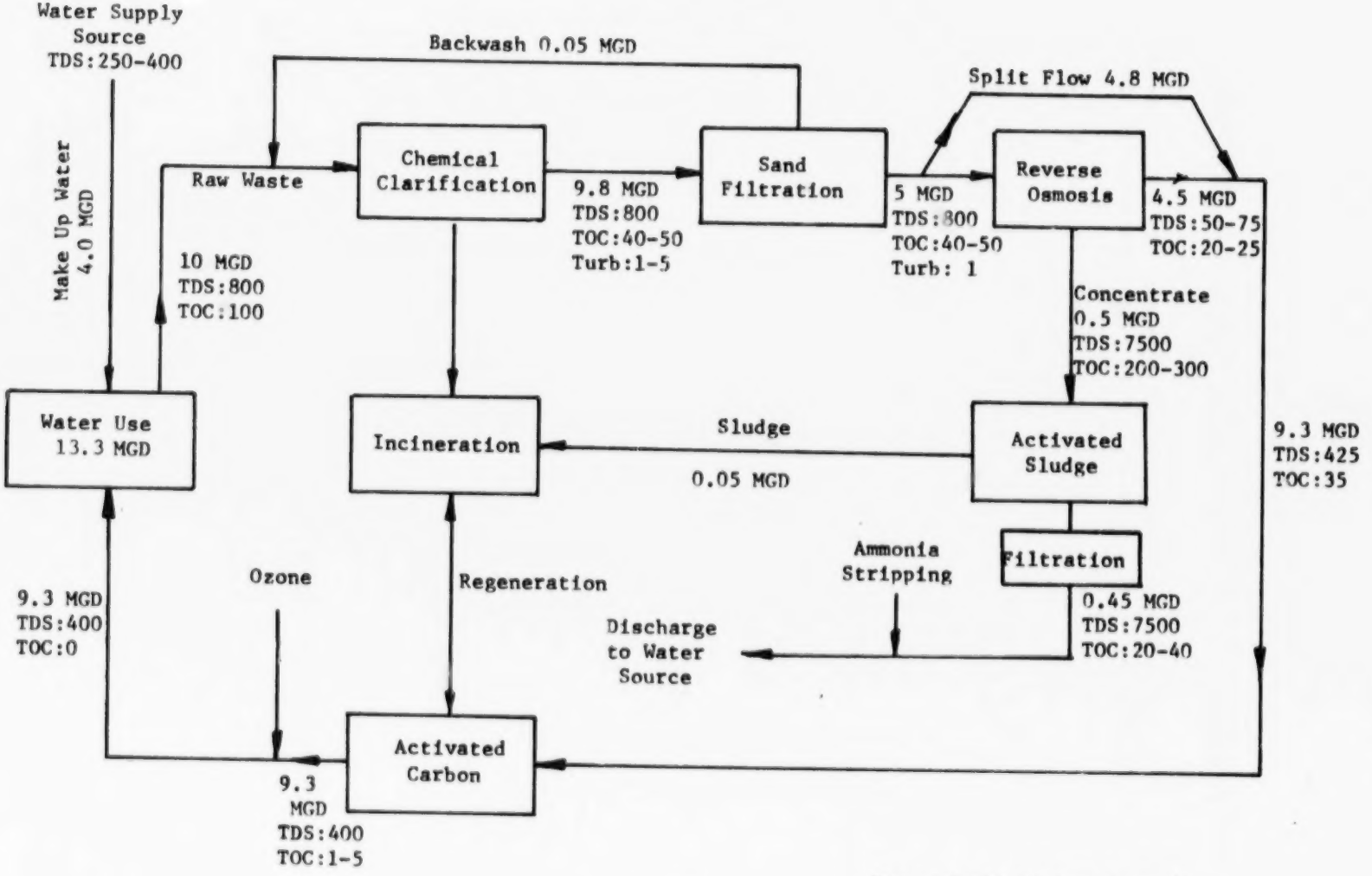

TDS and TOC Values in mg/l

FIGURE 14

RECOMMENDED TREATMENT SCHEME

has been described for a plant capacity of 10 mgd and economic projections have been drawn for the same. The flows handled by each subprocess and the expected water qualities before and after treatment are also shown on the flow diagram. Other assumptions, logistics and the general rules laid in the development of the above schematic are as follows:

1. The effluent after chemical clarification is free of most suspended material. The recommended chemicals are ferric chloride and alum as discussed earlier in the report. No extra pH adjustment is needed for this water before RO treatment.

2. Sand filtration of the chemically treated effluent is to be provided for reducing the membrane fouling by any residual suspended solids.

3. The sand filtered effluent will be split for RO treatment in such a proportion so as to produce less than 500 mg/l TDS in the combined effluent in accordance with USPHS standards.

4. A 90% recovery of the feed flow to RO was considered feasible based on the present study.

5. Only 50 to 60% removal of soluble organic carbon is expected through the RO treatment at a feed water recovery of 90%. However, the TDS removals can be expected to be in the range of 93 to 95%.

6. The concentrate from the RO treatment will be biologically oxidized and a minimum of 90% reduction in the total organic carbon can be achieved. The biologically treated effluent would remain concentrated in the total dissolved solids but would be rendered of such quality that is comparable to conventional secondary effluents in organic content. This effluent may have to be stripped of ammonia nitrogen and then can be discharged to the downstream end of the fresh water source under consideration.

7. The split flow when combined with the RO effluent will produce a water quality of less than 500 mg/l TDS and 30 to 40 mg/l TOC. This water will then be treated with activated carbon to reduce the dissolved organic matter.

8. Incineration facilities required for the regeneration of activated carbon will also serve the purpose of sludge disposal from chemical clarification, and wasted activated sludges.

9. The activated carbon treated effluent will have a TOC

value in the range of 1 to 5 mg/l. This remaining organic carbon will then be oxidized with ozone. The effluent water is not only expected to be free of organic matter but also will be rendered sterile because of ozone use and hence will be of potable quality.

From the above recommended flow scheme, a 93% overall recovery of reusable and potable water would be achieved. The additional make up water in each cycle of water use will be approximately 7%. The increase in dissolved solids in the treated water as compared to the original fresh water dissolved solids level may slightly increase the percentage of split flow treatment by reverse osmosis in the subsequent cycles. These considerations however will vary in specific situations and may be controlled as necessary. The above scheme would reduce the organic pollutant discharge to streams by almost eight-fold compared to the conventional secondary treatment discharges. The above claim can be verified as follows:

Assuming a TOC value of 15 mg/l for conventional secondary effluents, the lbs TOC discharge to streams from a 10 mgd plant =

$$= 15 \times 8.34 \times 10$$
$$= 1250 \text{ lbs TOC/day},$$

while only 4.5% of raw flow will be discharged to streams after the biological treatment of RO concentrates. Assuming a maximum TOC value of 40 mg/l for this effluent, the maximum lbs TOC discharged to streams from the proposed treatment scheme =

$$= 40 \times 8.34 \times 0.45$$
$$= 150 \text{ lbs TOC/day}$$

which is less than 15% of the lbs discharged from the conventional secondary effluent and is comparable to the tertiary treatment discharges.

Alternatively, it may also be possible to utilize the concentrated RO brines for the recovery of fertilizer products or may directly be able to apply to soil because of its rich mixture of nutrients. A feasibility study in this regard is recommended for future studies.

Economics of the Proposed Treatment Scheme

The economic attractiveness of the proposed treatment schematic will be analyzed by comparing its cost with the cost of water use and its treatment by conventional methods. These costs have been developed for a 10 mgd sewage handling facility. The total treatment costs for conventional and advanced methods have been utilized from published literature (9,22,23,24). The total operating cost of RO treatment alone has been assumed as 35¢/1000 gal. based on spiral wound RO membranes for a five mgd capacity RO plant (25). Sludge disposal costs

were not included in these comparisons as these are expected to be similar in both cases.

(A) Total Costs Without the Reuse of Water

Cost Item	Flow mgd	Unit Cost ¢/1000 gal	$/day
Fresh water use (based on 75% conversion of fresh water used to sewage)	13.33	10	1,333
Conventional primary and secondary treatment	10.0	12	1,200
Chlorination before discharge	10.0	1.0	100
			2,633

Therefore, the present cost of water use and treatment = $2,633/day or 26.3 ¢/1000 gal

(B) Total Costs with the Reuse and Treatment of Water

Cost Item	Flow mgd	Unit Cost ¢/1000 gal	$/day
Fresh water use after first cycle (based on 93% conversion of sewage to reusable water and 75% conversion of fresh water used to sewage)	4	10	400
Chemical clarification	10	7.5	750
Sand Filtration	10	3.0	300
Reverse Osmosis	5	35.0	1,750
Activated Carbon	9.3	8.5	790
Activated Sludge	0.5	12.0	60
Ammonia Stripping	0.5	10.0	50
Ozonation	9.8	5.0	490
			4,590

Hence, the proposed treatment costs = $4,590/day or 45.9 ¢/1000 gal

Therefore, comparing the costs in (A) and (B) Sections, it is evident that for only an additional 20¢/1000 gallons cost, it would be possible to convert our domestic wastes into reusable potable water supplies and also reduce the pollutant discharges by nearly eight-fold to the fresh water supplies as compared to the present conventional practices. Apart from the tangible benefits, there would emerge a large number of intangible benefits by implementing the above recommended scheme. These indirect benefits may be in the form of improved environment, availability of clean water for recreational activities, meeting of large demands of water supplies from the continued industrial growth. The intangible effects of these improvements on communities would be widely varied and a great stimulant to the general economy.

The economics for this treatment scheme can be looked at in another way. The complete cost of treatment alone with the recommended scheme is 45.9¢/1000 gallons, and when a cost recovery value because of the 93% water reuse is applied, the net treatment cost is only 32.6¢/1000 gallons. These treatment costs would further reduce with increase in plant size as well as the improvements in equipment and hardware to make this treatment scheme even more attractive.

However, it should be pointed out here that the above schematic will be most applicable for those domestic wastes that are amenable to efficient treatment via activated carbon. In the case of a domestic waste, such as for Milwaukee, which contains a large amount of ethanol that is not efficiently treatable by activated carbon, conventional primary and secondary treatment would be required prior to the upgrading of the secondary effluents by reverse osmosis, activated carbon and ozonation on a split flow basis. The cost of treatment n such cases would be higher than for the recommended flow scheme d would have to be evaluated for specific situations.

SECTION VIII

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SECTION X

APPENDICES

APPENDIX I

PRETREATMENT INVESTIGATION DATA

TABLE I-1

WASTE CHARACTERISTICS FOR VARIOUS TREATMENT PLANTS FOR MAY, 1970

Plant Analysis		Brookfield	Jones Island	Kenosha	Puetz Road	Racine	Waukesha
Flow	Avg	2.96	172.6	20.7	23.25	23.7	9.72
MGD	Range	1.99-6.27	126.6-205.2	15.9-29.1	15.9-42.9	170-30.7	7.15-11.2
pH	Avg.	7.3	7.7	7.8	7.5	7.7	7.6
	Range	7.2-7.4	7.3-8.1	7.7-8.0	7.3-7.6	7.5-7.9	7.4-8.2
Total Solids	Avg	--	944	--	1185	672	--
mg/1	Range	--	719-1155	--	891-1862	606-727	--
Suspended Solids	Avg	120	193	120	371	125	174
mg/1	Range	38-240	109-272	51-300	123-1092	68-209	85-370
BOD	Avg	75	192	71	296	64	140
mg/1	Range	32-110	80-295	36-158	166-491	39-115	64-228
COD	Avg	--	420	--	--	--	--
mg/1	Range	--	197-606	--	--	--	--

TABLE I-2

WASTE CHARACTERISTICS OF THE SAMPLES UTILIZED IN JAR TESTS

Plant Analysis	Brookfield	Jones Island	Kenosha	Puetz Road	Racine	Waukesha
pH range	7.7-7.8	7.0-7.2	7.3	7.3-8.1	6.8-7.4	7.45-7.65
Total Solids Range mg/l	989-1363	855-1312	696-1654	1070-1798	614-829	1037-1304
Suspended Solids Range mg/l	99-219	152-435	135-900	244-691	87-203	110-138
BOD Range mg/l	97-115	190-267	63-300	110-315	110-113	127-175
COD Range mg/l	187-275	470-661	199-1237	349-1421	247-312	266-311
TOC Range mg/l	∿60	192-225	∿75	110-408	∿113	∿104
TIC Range mg/l	∿90	46-50	∿56	64-70	∿51	∿76

TABLE I-3

JAR TESTS WITH $FeCl_3$

Dose mg/l	Waukesha[1] Turbidity	pH	Remarks	Brookfield[1] Turbidity	pH	Remarks
Raw	72 JTU	7.45		49 JTU	7.7	
50	37 JTU	--		30 JTU	--	
75	35 JTU	--		26 JTU	--	
100	23 JTU	--		20 JTU	--	
125	13 JTU	--	Extreme	13 JTU	--	Extreme
150	10 JTU	--	Clarity	8 JTU	--	Clarity

Dose mg/l	Waukesha[2] Turbidity	pH	Remarks	Brookfield[2] Turbidity	pH	Remarks
Raw	70 JTU	7.6		65 JTU	7.8	
75	28 JTU	6.75	Clear	32 JTU	6.9	Clear
100	22 JTU	6.7		28 JTU	6.9	
125	21 JTU	6.6	Extreme	16 JTU	6.8	Extreme
150	10 JTU	6.5	Clarity	14 JTU	6.75	Clarity
175	8 JTU	6.4		11 JTU	6.65	
200	7 JTU	6.3		11 JTU	6.50	

Dose mg/l	Waukesha[3] Turbidity	pH	Remarks	Brookfield[3] Turbidity	pH	Remarks
0	58 JTU	7.2		54 JTU	7.7	
50	45 JTU	7.0		28 JTU	7.2	
75	38 JTU	6.8		20 JTU	7.0	Extreme
100	22 JTU	6.8	Extreme	21 JTU	6.9	Clarity
125	17 JTU	6.5	Clarity	15 JTU	6.8	Achieved
150	6 JTU	6.6	Achieved	10 JTU	6.6	

1. Samples obtained on a Friday at 9:45 am for Waukesha and 10:15 am for Brookfield.
2. Samples obtained on a Monday at 12:30 pm for Waukesha and at 1:00 pm for Brookfield.
3. Samples obtained on a Thursday at 11:30 am for Waukesha and at 12:00 noon for Brookfield.

TABLE I-3 (cont.)

JAR TESTS WITH $FeCl_3$

Dose mg/l	Jones Island[1] Turbidity	pH	Remarks	Puetz Road[1] Turbidity	pH	Remarks
Raw	64 JTU	7.0		72 JTU	8.1	
50	35 JTU	7.0		55 JTU	7.4	
75	28 JTU	6.5		35 JTU	7.2	
100	20 JTU	6.6	Clarity	31 JTU	7.0	Clarity
125	15 JTU	6.6	Achieved	28 JTU	7.0	Achieved
150	8 JTU	6.2		15 JTU	6.2	

Dose mg/l	Jones Island[2] Turbidity	pH	Remarks	Puetz Road[2] Turbidity	pH	Remarks
Raw	72 JTU	6.8		82 JTU	7.0	
50	32 JTU	6.5		55 JTU	6.8	
75	23 JTU	6.4		35 JTU	6.7	
100	13 JTU	6.3	Clarity	28 JTU	6.6	
125	11 JTU	6.1	Achieved	20 JTU	6.5	Clarity
150	8 JTU	6.0		11 JTU	6.4	Achieved

1. Samples obtained on a Monday at 10:30 am for Jones Island and 11:15 am for Puetz Road.
2. Samples obtained on a Tuesday at 11:30 am for Jones Island and 12:45 for Puetz Road.

TABLE I-3 (cont.)

JAR TESTS WITH $FeCl_3$

Dose mg/l	Kenosha[1] Turbidity	pH	Remarks	Racine[1] Turbidity	pH	Remarks
Raw	55 JTU	7.3		78 JTU	7.4	
25	45 JTU	7.2		50 JTU	7.1	
50	42 JTU	7.0		43 JTU	6.9	
75	35 JTU	6.8		28 JTU	6.6	
100	15 JTU	6.6	Extreme	25 JTU	6.5	
125	11 JTU	6.5	Clarity	11 JTU	6.4	Clarity

Dose mg/l	Kenosha[2] Turbidity	pH	Remarks	Racine[2] Turbidity	pH	Remarks
Raw	unreadable	7.3		50 JTU	6.9	
25	~100 JTU	7.1		48 JTU	6.9	
50	80 JTU	6.9		34 JTU	6.7	
75	41 JTU	6.7		25 JTU	6.6	
100	25 JTU	6.7		19 JTU	6.4	Clarity
125	15 JTU	6.5	Clarity	14 JTU	6.2	

1. Samples obtained on a Monday at 9:45 am for Kenosha and at 10:30 am for Racine.

2. Samples obtained on a Thursday at 11:45 am for Kenosha and at 1:00 pm for Racine.

TABLE I-4

JAR TESTS WITH ALUM

Dose	Waukesha[1]			Brookfield[1]		
mg/l	Turbidity	pH	Remarks	Turbidity	pH	Remarks
Raw	75 JTU	7.45		41 JTU	7.7	
75	70 JTU	--		38 JTU	--	
100	65 JTU	--		40 JTU	--	
150	52 TJU	--		42 JTU	--	
200	17 JTU	--	Clarity	36 JTU	--	
250	21 JTU	--	Achieved	17 JTU	--	Clarity

Dose	Waukesha[2]			Brookfield[2]		
mg/l	Turbidity	pH	Remarks	Turbidity	pH	Remarks
Raw	75 JTU	7.6		65 JTU	7.8	
200	44 JTU	6.5		40 JTU	6.8	
205	23 JTU	6.5		45 JTU	6.8	
250	32 JTU	6.5		40 JTU	6.75	
275	33 JTU	6.5		35 JTU	6.70	
300	20 JTU	6.4	Clarity	27 JTU	6.65	
400	11 JTU	6.2	Achieved	12 JTU	6.5	Very Clear

Dose	Waukesha[3]			Brookfield[3]		
mg/l	Turbidity	pH	Remarks	Turbidity	pH	Remarks
Raw	65 JTU	7.2		55 JTU	7.4	
200	35 JTU	6.7		30 JTU	6.9	
225	23 JTU	6.6		28 JTU	6.7	
250	23 JTU	6.6		15 JTU	6.7	Clarity
275	13 JTU	6.5	Clarity	8 JTU	6.6	Achieved
300	11 JTU	6.3	Achieved	8	6.7	

1. Samples obtained on a Friday at 9:45 am for Waukesha and 10:15 am for Brookfield.
2. Samples obtained on a Monday at 12:30 pm for Waukesha and 1:00 pm for Brookfield.
3. Samples obtained on a Thursday at 11:30 am for Waukesha and 12:00 noon for Brookfield.

TABLE I-4 (cont.)

JAR TESTS WITH ALUM

Dose	Kenosha[1]			Racine[1]		
mg/l	Turbidity	pH	Remarks	Turbidity	pH	Remarks
Raw	46 JTU	7.3		70 JTU	7.4	
200	20 JTU	6.6	Clarity	20 JTU	6.7	Clarity
225	18 JTU	6.5	Achieved	14 JTU	6.6	Achieved
250	12 JTU	6.4		12 JTU	6.5	
275	11 JTU	6.3		12 JTU	6.4	
300	10 JTU	6.3		13 JTU	6.4	

Dose	Kenosha[2]			Racine[2]		
mg/l	Turbidity	pH	Remarks	Turbidity	pH	Remarks
Raw	unreadable	7.3		50 JTU	7.2	
200	29 JTU	6.7		21 JTU	6.5	
225	21 JTU	6.7		18 JTU	6.4	Clarity
250	19 JTU	6.6	Clarity	17 JTU	6.3	Achieved
275	11 JTU	6.5	Achieved	17 JTU	6.2	
300	7 JTU	6.5		13 JTU	6.2	

1. Samples obtained on a Monday at 9:45 am for Kenosha and at 10:30 am for Racine.

2. Samples obtained on a Thursday at 11:45 am for Kenosha and at 1:00 pm for Racine.

TABLE I-4 (cont.)

JAR TESTS WITH ALUM

Dose mg/l	Jones Island[1] Turbidity	pH	Remarks	Puetz Road[1] Turbidity	pH	Remarks
Raw	65 JTU	7.0		65 JTU	7.9	
200	23 JTU	6.7		28 JTU	7.2	
225	20 JTU	6.5		21 JTU	6.9	
250	15 JTU	6.5	Clarity	20 JTU	6.9	
275	13 JTU	6.4	Achieved	13 JTU	6.8	Clarity
300	11 JTU	6.3		11 JTU	6.8	Achieved

Dose mg/l	Jones Island[2] Turbidity	pH	Remarks	Puetz Road[2] Turbidity	pH	Remarks
Raw	64 JTU	6.8		80 JTU	6.9	
200	21 JTU	6.5		35 JTU	6.6	
225	25 JTU	6.4		22 JTU	6.6	
250	19 JTU	6.3	Clarity	19 JTU	6.5	Clarity
275	16 JTU	6.2	Achieved	20 JTU	6.5	Achieved
300	15 JTU	6.1		17 JTU	6.5	

1. Samples obtained on a Monday at 10:30 am for Jones Island and 11:15 am for Puetz Road.

2. Samples obtained on a Tuesday at 11:30 am for Jones Island and 12:45 pm for Puetz Road.

TABLE I-5

JAR TESTS WITH LIME (CaO)

Dose mg/l	Waukesha[1] Turbidity	pH	Remarks	Brookfield[1] Turbidity	pH	Remarks
0	70 JTU	7.6		65 JTU	7.8	
100	55 JTU	8.9	No acceptable	65 JTU	9.0	No acceptable
200	45 JTU	9.4	clarity was	52 JTU	9.3	clarity was
300	45 JTU	9.4	achieved	45 JTU	9.4	achieved
400	50 JTU	--		44 JTU	9.5	
450	35 JTU	9.4		70 JTU	--	
500	32 JTU	10.2		35 JTU	9.6	
500*	8 JTU	9.1	Good	>35 JTU	>9	All effluent
600	7 JTU	9.3	clarity	" JTU	"	samples
700	6 JTU	9.5	achieved up to	" JTU	"	extremely
800	8 JTU	11.6	800 mg/l CaO	" JTU	"	turbid.
900	18 JTU	12.0		" JTU	"	
1000	40 JTU	12.0		" JTU	"	

* Samples were first run at concentrations between 500 mg/l and 1000 mg/l, and one day later were run at concentrations between 100 mg/l and 500 mg/l.

1. Samples obtained on a Monday at 12:30 pm for Waukesha and 1:00 pm for Brookfield.

TABLE I-6

JAR TESTS WITH PRIMAFLOC A-23

Dose mg/l	Waukesha[1] Turbidity	pH	Brookfield[1] Turbidity	pH
Raw	70 JTU	7.6	65 JTU	7.8
.15	100 JTU	7.4	56 JTU	7.5
.20	80 JTU	7.5	60 JTU	7.5
.25	96 JTU	7.5	65 JTU	7.7
.30	80 JTU	7.5	62 JTU	7.7
.40	82 JTU	7.5	28 JTU	7.7
.50	62 JTU	7.5	28 JTU	7.7
.60	60 JTU	7.4	40 JTU	7.6
.70	60 JTU	7.5	40 JTU	7.6
1.00	57 JTU	7.5	35 JTU	7.6
1.10	60 JTU	7.4	32 JTU	7.6
1.20	58 JTU	7.5	30 JTU	7.6
1.30	60 JTU	7.4	30 JTU	7.6

Dose mg/l	Waukesha[2] Turbidity	pH	Brookfield[2] Turbidity	pH
Raw	65 JTU	7.6	48 JTU	7.6
1	38 JTU	7.6	35 JTU	
2	41 JTU	7.6	35 JTU	
3	43 JTU	7.5	35 JTU	
4	40 JTU	7.5	35 JTU	
5	39 JTU	7.1	30 JTU	

1. Samples obtained on a Monday at 12:30 pm for Waukesha and at 1:00 pm for Brookfield.

2. Samples obtained on a Thursday at 11:30 am for Waukesha and at 12:00 noon for Brookfield.

TABLE I-7

JAR TESTS WITH ALUM & A23

Alum Dose mg/l	A23 Dose mg/l	Puetz Road[1] Turbidity	pH
Raw	Raw	65 JTU	7.9
150	2	36 JTU	6.8
175	2	38 JTU	6.9
175	1	33 JTU	7.1
200	1	28 JTU	7.0
200	.5	40 JTU	7.1
225	.5	19 JTU	7.1

Alum Dose mg/l	A23 Dose mg/l	Puetz Road[2] Turbidity	pH	Remarks	Jones Island[2] Turbidity	pH	Remarks
175	.5	29 JTU	6.4		22 JTU	6.2	Clarity
175	1.0	21 JTU	6.6	Clarity	20 JTU	6.4	Achieved
175	2.0	20 JTU	6.7	Achieved	18 JTU	6.4	
200	.5	18 JTU	6.6		20 JTU	6.5	
200	1.0	20 JTU	6.6		20 JTU	6.5	
200	2.0	19 JTU	6.7		12 JTU	6.5	

1. Sample obtained on a Monday at 11:45 am.

2. Samples obtained on Tuesday at 11:30 am for Jones Island and 12:45 pm for Puetz Road.

TABLE I-8

JAR TESTS WITH ALUM & C31

Alum Dose mg/l	C31 Dose mg/l	Jones Island[1] Turbidity	pH	Remarks
200	.5	18 JTU	6.9	Clarity
200	1.0	18 JTU	6.9	
200	2.0	12 JTU	6.8	

Alum Dose mg/l	C31 Dose mg/l	Jones Island[2] Turbidity	pH	Remarks	Puetz Road[2] Turbidity	pH	Remarks
100	.5	34 JTU	6.5		35 JTU	6.7	
100	1.0	29 JTU	6.7		35 JTU	6.7	
125	.5	22 JTU	6.7		32 JTU	6.8	
125	1.0	30 JTU	6.7		33 JTU	6.8	
150	.5	19 JTU	6.6	Clarity	20 JTU	6.7	Clarity
150	1.0	20 JTU	6.6		20 JTU	6.7	

1. Sample obtained on a Monday from Jones Island at 10:30 am.

2. Samples obtained on a Tuesday from Jones Island at 11:30 am and at Puetz Road at 12:45 pm.

TABLE I-9

JAR TESTS WITH $FeCl_3$ & A23

$FeCl_3$ Dose mg/l	A23 Dose mg/l	Jones Island[1] Turbidity	Jones Island[1] pH	Puetz Road[1] Turbidity	Puetz Road[1] pH
50	.5	29 JTU	6.4	51 JTU	6.6
50	1.0	25 JTU	6.6	52 JTU	6.7
50	2.0	30 JTU	6.7	54 JTU	6.8
75	.5	21 JTU	6.7	42 JTU	6.7
75	1.0	18 JTU	6.6	34 JTU	6.7
75	2.0	22 JTU	6.6	42 JTU	6.6

$FeCl_3$ Dose mg/l	A23 Dose mg/l	Kenosha[2] Turbidity	Kenosha[2] pH	Racine[2] Turbidity	Racine[2] pH
25	.25	43 JTU	7.1	61 JTU	7.1
25	.5	35 JTU	7.1	50 JTU	7.1
25	1.0	35 JTU	7.1	52 JTU	7.1
50	.25	25 JTU	6.9	25 JTU	6.9
50	.5	27 JTU	6.9	23 JTU	6.9
50	1.0	22 JTU	6.9	30 JTU	6.9

1. Samples obtained on a Tuesday at 11:30 am for Jones Island and at 12:45 pm for Puetz Road.

2. Samples obtained on a Monday at 9:45 am for Kenosha and at 10:30 am for Racine.

TABLE I-10

JAR TESTS WITH $FeCl_3$ & C31

$FeCl_3$ Dose mg/l	C31 Dose mg/l	Jones Island[1] Turbidity	pH
50	.5	39 JTU	6.9
50	1.0	35 JTU	7.0
50	2.0	34 JTU	7.0

$FeCl_3$ Dose mg/l	C31 Dose mg/l	Jones Island[2] Turbidity	pH	Remarks	Puetz Road[2] Turbidity	pH	Remarks
25	.5	35 JTU	6.6		52 JTU	6.7	
25	1.0	35 JTU	6.9		60 JTU	6.9	
25	1.5	33 JTU	6.9		60 JTU	7.0	
25	2.0	35 JTU	6.9		60 JTU	6.9	
25	3.0	25 JTU	6.9		46 JTU	7.0	
25	4.0	26 JTU	6.9		45 JTU	7.0	

$FeCl_3$ Dose mg/l	C31 Dose mg/l	Kenosha[3] Turbidity	pH	Remarks	Racine[3] Turbidity	pH	Remarks
25	.5	35 JTU	7.1		53 JTU	7.2	
25	1.0	24 JTU	7.1		50 JTU	7.2	
25	2.0	28 JTU	7.0		45 JTU	7.2	
50	.5	16 JTU	6.8	clarity	38 JTU	7.0	
50	1.0	15 JTU	6.8	achieved	31 JTU	7.0	
50	2.0	11 JTU	6.8		21 JTU	6.9	

1. Sample obtained on a Monday from Jones Island at 10:30 am.
2. Samples obtained on a Tuesday from Jones Island at 11:30 am and Puetz Road at 12:45 pm.
3. Samples obtained on a Monday from Kenosha at 9:45 am and Racine at 10:30 am.

TABLE I-11

JAR TESTS WITH $FeCl_3$ AND HERCOFLOC 822A

$FeCl_3$ Dose mg/l	822A Dose mg/l	Kenosha[1] Turbidity	pH	Remarks	Racine[1] Turbidity	pH	Remarks
Raw	Raw	41 JTU	7.3		65 JTU	7.4	
25	.25	31 JTU	7.1		46 JTU	7.1	
25	.50	31 JTU	7.0		46 JTU	7.1	
25	.75	30 JTU	7.1		47 JTU	7.0	
25	1.00	31 JTU	7.0		48 JTU	7.1	
25	2.00	31 JTU	7.0		48 JTU	7.1	

JAR TESTS WITH $FeCl_3$ AND HERCOFLOC 810-C

$FeCl_3$ Dose mg/l	810-C Dose mg/l	Kenosha[1] Turbidity	pH
25	.5	30 JTU	7.2
25	1.0	25 JTU	7.2
25	2.0	27 JTU	7.2
25	3.0	24 JTU	7.2

$FeCl^3$ Dose mg/l	810-C Dose mg/l	Kenosha[2] Turbidity	pH	Remarks	Racine[2] Turbidity	pH	Remarks
25	.5	86 JTU	6.9		35 JTU	6.9	
25	1.0	79 JTU	7.0		35 JTU	6.7	
25	1.0	64 JTU	7.0		40 JTU	6.8	
50	.5	46 JTU	6.9		30 JTU	6.6	
50	1.0	34 JTU	6.9		24 JTU	6.6	
50	2.0	35 JTU	6.9		24 JTU	6.6	

1. Samples obtained on a Monday at 9:45 am for Kenosha and and 10:30 am for Racine.
2. Samples obtained on a Thursday at 11:45 am for Kenosha and 1:00 pm for Racine.

TABLE I-12

JAR TESTS WITH $FeCl_3$ AND 675A

$FeCl_3$ Dose[3] mg/l	675A Dose mg/l	Kenosha[1] Turbidity	pH	Remarks	Racine[1] Turbidity	pH	Remarks
25	.25	35 JTU	7.1		48 JTU	7.0	
25	.50	26 JTU	7.1		44 JTU	7.0	
25	1.00	25 JTU	7.1		42 JTU	7.0	
50	.25	24 JTU	6.9		36 JTU	6.8	
50	.50	22 JTU	6.8		39 JTU	6.8	
50	1.00	22 JTU	6.8		38 JTU	6.8	

JAR TESTS WITH $FeCl_3$ and MAGNIFLOC 905-N

$FeCl_3$ Dose mg/l	905N Dose mg/l	Kenosha[2] Turbidity	pH	Remarks	Racine[2] Turbidity	pH	Remarks
25	.5	79 JTU	6.9		41 JTU	6.8	
25	.75	70 JTU	7.0		38 JTU	6.9	
25	1.00	72 JTU	7.0		42 JTU	6.9	
25	1.25	68 JTU	7.0		41 JTU	6.9	
25	1.50	70 JTU	7.0		37 JTU	6.9	
25	2.00	62 JTU	7.0		38 JTU	6.9	

1. Samples obtained on a Monday from Kenosha at 9:45 am and at Racine at 10:30 am.

2. Samples obtained on a Thursday from Kenosha at 11:45 am and at Racine at 1:00 pm.

TABLE I-13

JAR TESTS WITH $FeCl_3$ AND ALUM

$FeCl_3$ Dose mg/l	Alum Dose mg/l	Kenosha[1] Turbidity	pH	Remarks	Racine[1] Turbidity	pH	Remarks
25	50	65 JTU	6.9		48 JTU	6.7	
25	100	24 JTU	6.8		25 JTU	6.6	
25	125	20 JTU	6.8	Clarity	21 JTU	6.5	
50	25	35 JTU	6.8		32 JTU	6.6	
50	50	28 JTU	6.8		26 JTU	6.6	
50	100	11 JTU	6.7	Clarity	11 JTU	6.6	Clear

$FeCl_3$ Dose mg/l	Alum Dose mg/l	Racine[1] Turbidity	pH	Remarks
10	75	49 JTU	6.8	
10	100	36 JTU	6.7	
10	125	28 JTU	6.6	
15	75	44 JTU	6.7	
15	100	25 JTU	6.7	
15	125	11 JTU	6.6	Clarity

1. Samples obtained on a Thursday at 11:45 am for Kenosha and at 1:00 pm for Racine.

TABLE I-14

JAR TESTS WITH $FeCl_3$ & PRIMAFLOC C7

$FeCl_3$ Dose mg/l	C7 Dose mg/l	Kenosha[1] Turbidity	pH	Remarks	Racine[1] Turbidity	pH	Remarks
25	.25	90 JTU	7.0		35 JTU	7.0	
25	.50	65 JTU	7.0		35 JTU	7.0	
25	.75	61 JTU	7.0		35 JTU	7.0	
25	1.00	60 JTU	7.0		34 JTU	7.0	
25	1.25	62 JTU	7.0		36 JTU	7.0	
25	1.50	48 JTU	7.0		36 JTU	7.0	

1. Samples obtained on a Thursday at 11:45 am for Kenosha and at 1:00 pm for Racine.

Bio-Treatment of the Settled Sewage RO Concentrate

The ten-fold concentrate obtained from the RO experiments utilizing the tubular system as discussed earlier was subjected to biological oxidation in the pilot activated sludge units. The units were seeded with returned sludge from the Milwaukee Sewage Treatment Plant and an aeration time of 24 hours was provided. The units were fed once a day in the mornings. In an effort to collect the maximum amount of acclimated sludge from this study for setting up a batch-kinetic study at high mixed liquor solid levels, little or no sludge volume was wasted from the aeration units and only the settled supernatant after one hour sedimentation was wasted at the feeding time. However, attempts to collect a second batch of RO brine from the settled sewage failed due to module plugging problems (as described in the main body of this report), and therefore the biological treatment feasibility data for settled sewage was limited to only one experiment. Also, no further attempts were made to collect more brine from settled sewage as it had already been indicated that prior chemical treatment of the raw sewage would be necessary even when tubular RO systems were utilized. Hence, future experiment program priorities were shifted towards obtaining data on concentrates obtained from the RO treatment of chemically treated and settled sewages.

However, significant amounts of data had emerged from the above described experiment, and it was shown that it was feasible to biologically oxidize the RO concentrate stream. TOC removals of the order of 85 to 90% were achieved in the biologically oxidized and settled effluent (Table II-1). No acclimitization of the activated sludge biota was needed for the concentrate stream and the returned sludge from the Milwaukee Sewage Treatment Plant was found to be suitable for the system start-up.

A typical oxygen uptake curve is shown in Figure II-1. Immediately after feeding, the oxygen uptake rate would increase markedly as expected. An oxygen uptake rate as high as 187 mg/l/hr occurred immediately after feeding and decreased to approximately 30/mg/l/hr after the 24 hour aeration period. The mixed liquor suspended solid concentrations utilized in the aeration units ranged between 2800 and 4700 mg/l (Table II-1). The loading rates in terms of #TOC/#MLVSS/day varied between 0.21 and 0.37.

The settling characteristics of the activated sludge were found to be quite good and the SVI index ranged between 39 and 104. A typical settling curve is shown in Figure II-2, and the settling data is presented in Table II-2. Settling velocities of the sludge were good and ranged between 6 to 15 ft/hr. The suspended solids content of the settled effluent ranged between 48 and 96 mg/l in the pilot units but this is expected to improve significantly in large size plant operation.

TABLE II-1

BIOLOGICAL OXIDATION DATA - SETTLED SEWAGE CONCENTRATE[1]

MLSS mg/l	MLVSS mg/l	pH	TOC Loading #TOC/#MLVSS/day	% TOC Removal per 24 hr Aeration	Effluent S.S.[2] mg/l	O_2 Uptake Rate after 24 hr aeration Period mg/l/hr
2790	2010	8.0	0.37	85.0	90	29
3590	2440	8.3	0.31	89.5	96	26
4700	3200	8.3	0.25	90.0	86	--
3600	2310	8.3	0.21	87.5	48	32

1 TOC of RO concentrate : 710 mg/l
2 After 24 hour aeration and one hour settling

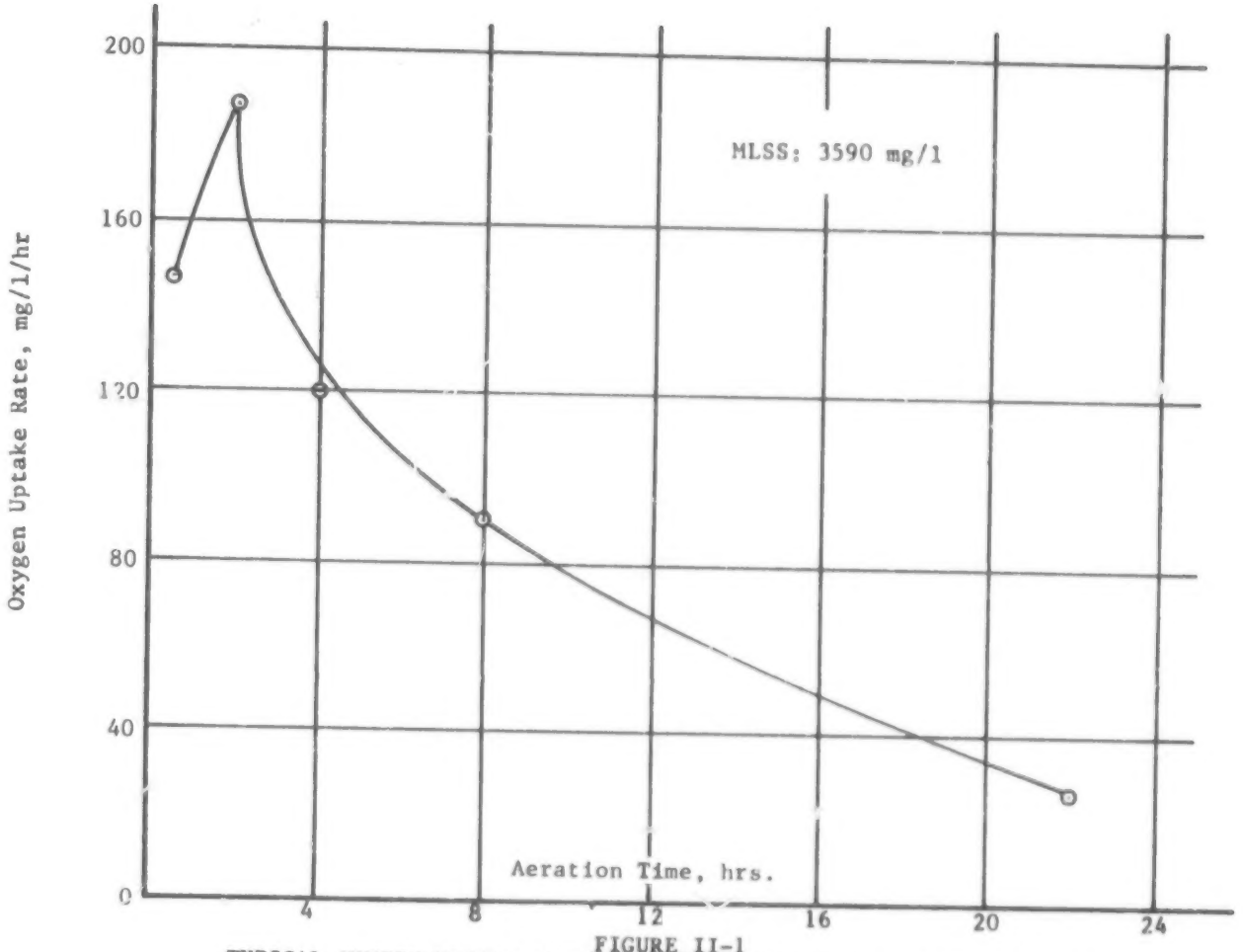


FIGURE II-1

TYPICAL OXYGEN UPTAKE CURVE FOR RO CONCENTRATE - SETTLED SEWAGE

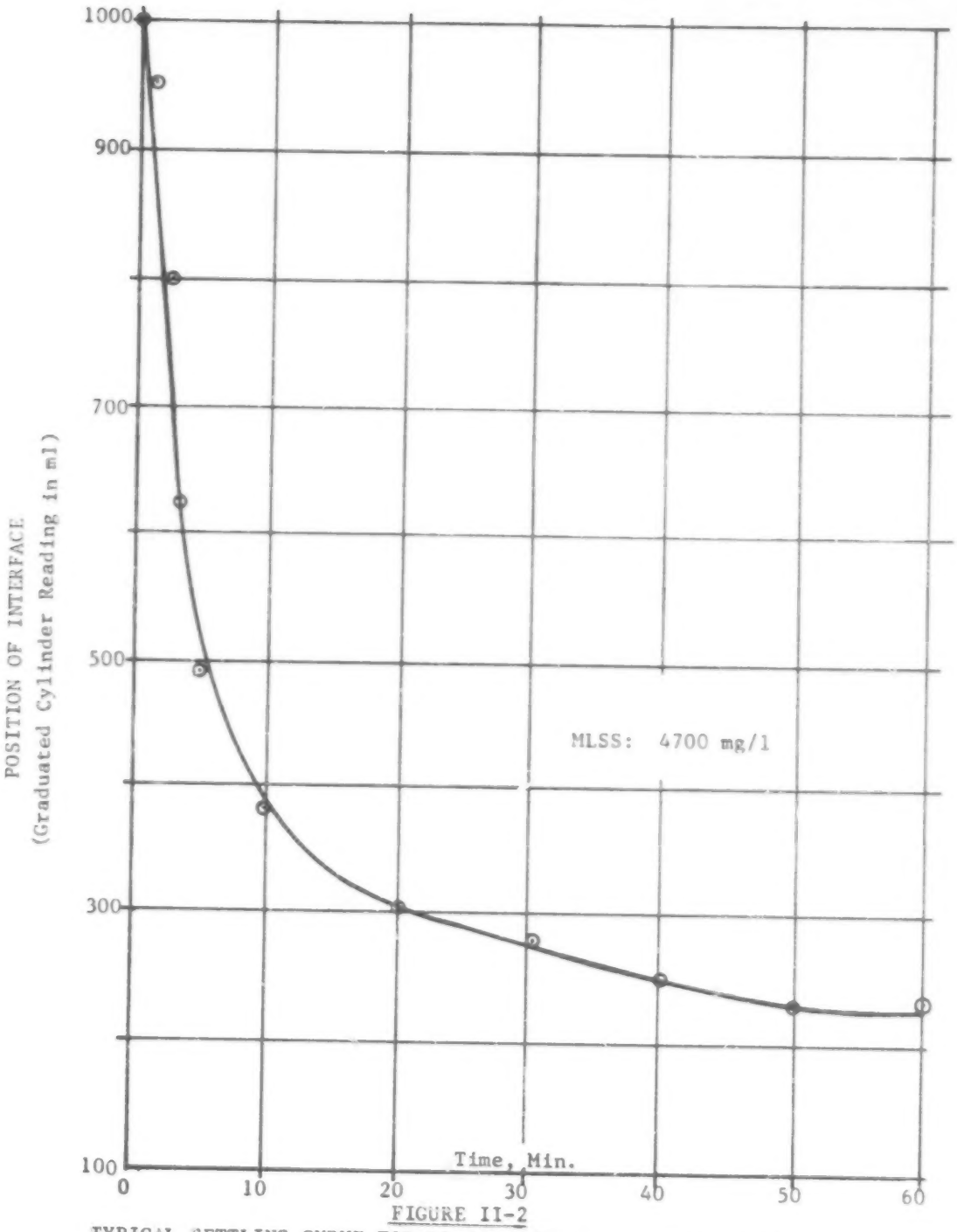


FIGURE II-2

TYPICAL SETTLING CURVE FOR RO CONCENTRATE - SETTLED SEWAGE

TABLE II-2

SETTLING TEST DATA - SETTLED SEWAGE CONCENTRATE

MLSS mg/l	Aeration Time hours	SVI	Settling Velocity ft/hr
2790	24	104	9.3
3590	24	72	8.5
4700	24	57	6.2
3600	24	39	15.0

TABLE II-3

CHEMICALLY TREATED SEWAGE CONCENTRATE[1] - BATCH KINETIC RUN #1
BIO-OXIDATION DATA

Aeration Time hrs.	Effluent Quality at Various MLSS Levels & Aeration Periods											
	1500			2500			3000			4000		
	pH Units	Fil.[2] TOC mg/l	O_2 Uptake Rate mg/l	pH Units	Fil.[2] TOC mg/l	O_2 Uptake Rate mg/l/hr	pH Units	Fil.[2] TOC mg/l	O_2 Uptake Rate mg/l/hr	pH Units	Fil.[2] TOC mg/l	O_2 Uptake Rate mg/l/hr
0.25	8.3	667	39.4	8.05	606	105.5	8.2	553	103.0	8.2	700	35.1
0.50	8.2	639	31.9	8.15	648	79.7	8.1	425	98.5	8.1	608	111.4
1.5	8.2	485	22.7	8.2	456	62.8	8.0	321	36.0	8.3	500	75.0
3.0	8.2	455	18.8	8.25	307	39.5	8.2	210	36.6	8.2	317	65.5
6.0	8.2	350	10.1	8.3	240	35.1	8.2	111	19.1	8.2	170	60.5
8.0	8.25	361	11.2	8.4	150	24.5	8.25	100	20.9	8.25	133	26.7
15.0	8.25	260	7.1	8.4	110	9.0	8.25	85	9.4	8.25	120	19.0
24.0	8.3	218	11.2	8.4	104	5.8	8.3	133	6.7	8.3	90	6.0

1. TOC of RO concentrate: 710 mg/l.
2. Samples filtered through #1 Whatman filter paper.

TABLE II-4

CHEMICALLY TREATED SEWAGE CONCENTRATE[1] - BATCH KINETIC RUN NO. 2
BIO-OXIDATION DATA, UNIT 1

Day & Time After Feeding		pH Units	MLSS mg/l	MLVSS mg/l	Filtered[2] TOC mg/l	O_2 Uptake Rate mg/l/hr	Unfiltered Effluent[3] TOC, mg/l	Effluent[3] Suspended Solids mg/l	Sludge Concentration % Total Solids
I	2 hr	8.45	3700	2800	166	90.0	--	--	--
	6 hr	8.25	4125	2750	112	63.5	--	--	1.72
	24 hr	8.05	3200	2040	89	25.7	249	440	2.80
II	1.5 hr	8.05	3600	--	115	57.6	--	--	--
	4.0 hr	8.0	4080	2630	87	41.1	--	--	3.39
	16 hr	8.05	4530	2860	69	19.5	130	162	2.56
III	1.25 hr	8.0	4230	--	101	69.0	--	--	--
	5.0 hr	7.85	4270	--	83	34.7	133	210	3.58
	16 hr	7.9	3310	2000	64	16.7	127	--	3.32
IV	15.0 hr	7.9	3080	1810	64	15.2	162	234	3.50
V	15.0 hr	7.8	3370	1880	64	27.0	--	--	--

1. TOC of the RO concentrate 710 mg/l on 1st day and 810-830 mg/l thereafter.
2. TOC of the mixed liquor sample after filtration through #1 Whatman filter paper.
3. Effluent after one hour settling.

TABLE II-5

CHEMICALLY TREATED SEWAGE CONCENTRATE[1] - BATCH KINETIC RUN #2
BIO-OXIDATION DATA, UNIT 2

Day & Time After Feeding		pH Units	MLSS mg/l	MLVSS mg/l	Filtered[2] TOC mg/l	O_2 Uptake Rate mg/l/hr	Unfiltered Effluent[3] TOC, mg/l	Effluent[3] Suspended Solids mg/l	Sludge Concentration % Total Solids
I	2 hr	8.25	7150	5317	154	90.8	--	--	--
	6 hr	8.2	7417	5400	102	69.6	--	--	--
	24 hr	8.2	7420	5140	88	26.6	--	--	--
II	1.5 hr	8.05	4460	--	99	50.1	--	--	--
	6 hr	8.2	4760	3460	80	34.5	117	150	2.23
	16 hr	8.1	4730	3270	67	24.6	114	102	2.41
III	1.25 hr	7.9	4920	--	82	64.0	--	--	--
	5 hr	7.9	4540	--	75	45.7	103	100	2.77
	16 hr	7.8	5350	3470	71	26.1	117	147	2.91
IV	15 hr	7.7	3860	2380	67	31.5	125	136	3.64
V	15 hr	7.8	4770	2980	58	23.0	105	123	3.67

1. TOC of the RO concentrate 710 mg/l on 1st day and 810-830 mg/l thereafter.
2. TOC of the mixed liquor sample after filtration through #1 Whatman filter paper.
3. Effluent after one hour settling.

TABLE II-6

CHEMICALLY TREATED SEWAGE CONCENTRATE[1] - BATCH KINETIC RUN #2
BIO-OXIDATION DATA, UNIT 3 .

Day & Time After Feeding		pH Units	MLSS mg/l	MLVSS mg/l	Filtered[2] TOC mg/l	O_2 Uptake Rate mg/l/hr	Unfiltered Effluent[3] TOC, mg/l	Effluent[3] Suspended Solids mg/l	Sludge Concentration % Total Solids
I	2 hr	8.15	10317	7800	192	102.0	---	---	---
	6 hr	8.25	10250	7580	141	87.4	---	---	---
	24 hr	8.10	9710	7160	109	33.4	---	---	---
II	1.5 hr	8.15	5840	---	117	48.9	---	---	---
	6 hr	8.05	5880	---	100	36.0	132	94	2.39
	16 hr	7.9	5440	3750	73	39.0	108	127	3.40
III	1.25 hr	7.95	5160	---	86	65.0	---	---	---
	5 hr	7.9	5480	---	73	52.8	118	135	4.54
	16 hr	7.8	6320	2050	79	45.4	128	147	3.00
IV	15 hr	7.7	5620	3610	75	56.1	146	160	3.38
V	15 hr	7.8	5760	3590	58	28.0	101	110	2.67

1. TOC of the RO concentrate 710 mg/l on 1st day and 810-830 mg/l thereafter.
2. TOC of the mixed liquor sample after filtration through #1 Whatman filter paper.
3. Effluent after one hour settling.

TABLE II-7

CHEMICALLY TREATED SEWAGE CONCENTRATE[1] - BATCH KINETIC RUN #2
BIO-OXIDATION DATA, UNIT 4

Day & Time After Feeding		pH Units	MLSS mg/1	MLVSS mg/1	Filtered[2] TOC mg/1	O_2 Uptake Rate mg/1/hr	Unfiltered Effluent[3] TOC, mg/1	Effluent[3] Suspended Solids mg/1	Sludge Concentration % Total Solids
I	2 hr	8.3	7200	5800	114	78.0	--	--	--
	6 hr	8.35	6833	4900	84	60.0	--	--	--
	24 hr	8.2	6830	5190	83	30.0	--	--	--
II	1.5 hr	8.1	3850	--	106	51.0	--	--	--
	6 hr	8.0	4790	--	90	42.0	138	155	2.36
	16 hr	8.0	4370	3010	73	32.0	113	115	2.72
III	1.25 hr	8.05	4860	--	117	52.5	--	--	--
	5 hr	7.9	5010	--	70	29.0	123	132	2.88
	16 hr	7.85	4640	3000	72	30.2	125	153	3.10
IV	15 hr	7.7	4300	2700	70	20.7	141	154	3.80
V	15 hr	7.8	5890	3620	63	25.7	111	113	3.67

1. TOC of the RO concentrate 710 mg/1 on 1st day & 810-830 thereafter.
2. TOC of the mixed liquor sample after filtration through #1 Whatman filter paper.
3. Effluent after one hour settling.

TABLE II-8

CHEMICALLY TREATED SEWAGE CONCENTRATE[1] - BATCH KINETIC RUN #3

BIO-OXIDATION DATA

Aeration Time hrs	Effluent Quality at Various Mixed Liquor Levels and Aeration Periods											
	MLSS 4000 mg/l MLVSS 2100 mg/l			MLSS 5000 mg/l MLVSS 2900 mg/l			MLSS 5500 mg/l MLVSS 3200 mg/l			MLSS 6000 mg/l MLVSS 3450 mg/l		
	pH Units	Fil.[2] TOC mg/l	O_2 Uptake Rate mg/l	pH Units	Fil.[2] TOC mg/l	O_2 Uptake Rate mg/l/hr	pH Units	Fil.[2] TOC mg/l	O_2 Uptake Rate mg/l/hr	pH Units	Fil.[2] TOC mg/l	O_2 Uptake Rate mg/l/hr
0.5	7.8	297	114.0	7.9	201	164.0	7.8	98	111.3	7.9	165	127.0
1.5	7.85	195	71.4	7.9	92	65.4	7.8	79	52.6	7.85	83	58.3
3.5	7.95	115	40.2	8.0	77	35.5	7.95	84	34.7	8.1	80	37.7
5.5	8.0	85	32.4	8.05	72	30.0	8.0	65	28.6	8.0	67	30.0
7.5	8.0	83	23.0	8.0	70	31.3	8.0	68	26.8	8.1	69	24.4
15.0	8.0	64	21.3	8.0	72	25.1	8.05	79	24.9	8.05	67	23.6
23.0	8.1	71	18.6	8.1	65	9.4	8.1	71	9.7	8.15	67	7.4

1. TOC of the RO concentrate: 810-830 mg/l
2. Samples filtered through #1 Whatman filter paper

APPENDIX III

PERMEATE INVESTIGATION DATA

Gas Chromatograph Investigations

A series of gas chromatographic tests were performed on samples from tests where raw sewage was treated by reverse osmosis. The initial intention of the gas chromatography was to identify the major organic component(s) in the permeate water and measure the amount present. When the nature and amount of the major component was recognized, additional gas chromatographic work was done on feed and brine samples from the reverse osmosis tests and on several samples of raw sewage from the Milwaukee sewage plant and other local sewage plants.

The paper "Removal of Organics from Wastewater by Reverse Osmosis" by W.A. Davel, Jr., T. Helfgott, and E.J. Genetelli presented at the American Chemical Society Meeting held in Chicago, Illinois on September 13-18, 1970 was utilized in this work. This paper presents data on the permeability of various classes of compounds and presents three general properties that enhance the permeability of organic molecules: low molecular weight, small molecular size as determined by steric geometry, and the ability to form hydrogen bonds. The data indicated that compounds in the permeate would probably not contain more than four carbons (if an aliphatic), would probably be a linear molecule rather than branched and would probably be polar. Specific classes of compounds that might be present are carboxylic acids, alcohols, amines and amides. Aldehydes, ketones, sulfones and esters are expected to be less permeable. Phenol forms hydrogen bonds so strongly that it is very permeable in spite of its molecular weight and size. The classes of compounds most likely to be found in the permeate can be readily separated and measured in mg/l quantities by gas chromatography.

Instrumentation and Columns: the gas chromatography work was done with a Barber-Colman Series 5000 gas chromatograph. This is a dual column instrument equipped with two flame ionization detectors and a single six-port thermal conductivity detector. Helium was used as the carrier gas. The injector and detector temperatures were maintained at 225°C for most tests (a malfunctioning voltage controller caused the detector temperature to vary at times). Instrument conditions are listed on each chromatogram in the appendix. A Barber-Colman recorder equipped with a disc integrator was used to record the chromatograms.

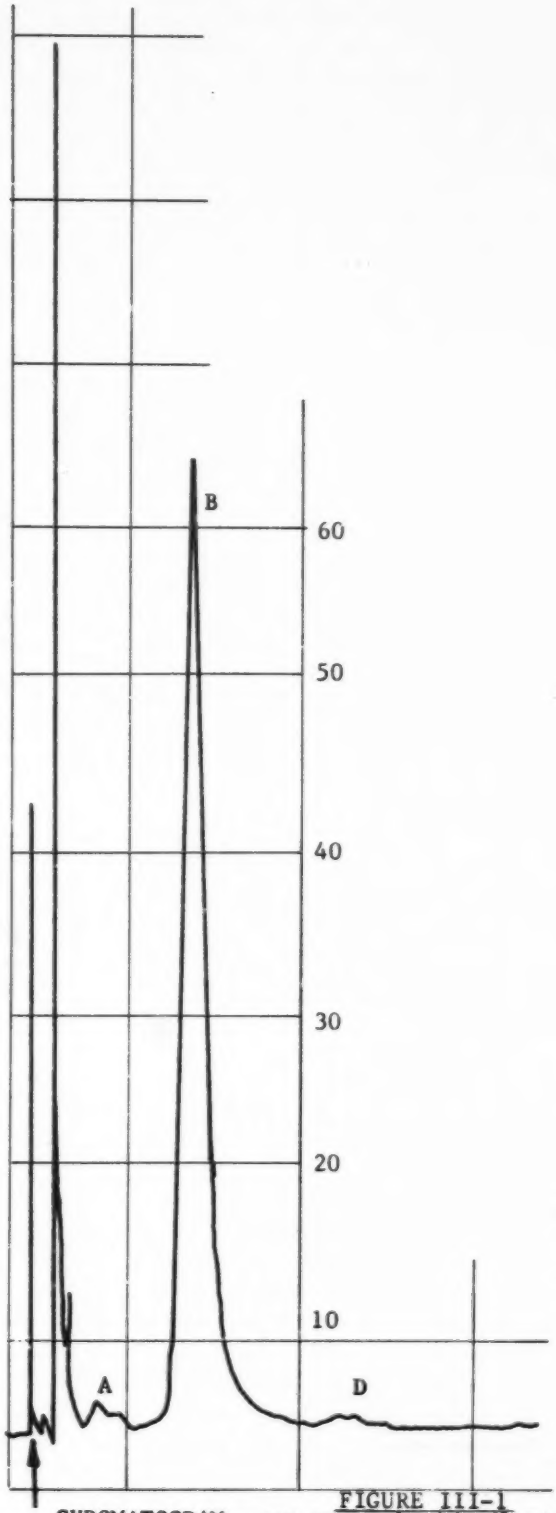
Three packings were used in these tests: Porapak Q, Porapak S, and Porapak Q-S; all 60/80 mesh. The Q and the S columns were made of 6 foot x 1/4 inch O.D. stainless steel tubing. The Porapak Q-S column was made of 3 foot x 1/8 inch O.D. stainless steel tubing. The columns were conditioned at 210°C before use and occasionally during the series of tests. Porapak Q is well suited for the separation of low molecular weight organics. Porapak Q-S is a silanized form of Porapak Q; retention times are about the same for both Q and Q-S packings. Porapak S is a more polar type of Porapak; polar compounds, such as alcohols and organic acids, elute later from Porapak S than from Porapak Q. The retention time for non-polar compounds is about the same for all three packings used.

Sample Preparation: The samples which were chromatographed were stored under refrigeration. The reverse osmosis feed, brine, and permeate samples and the sewage plant effluent samples were stored and tested as received. The raw sewage samples were clarified by centrifugation as soon as they were received and were chromatographed immediately or refrigerated until the tests could be run.

Before it was determined that direct aqueous injection of the samples was possible, large samples of permeate were saved for future concentration of the organic fraction. Two five gallon samples of the 1/13/71 permeate and one five gallon sample of the 1/20/71 permeate were stored in glass carboys at room temperature. One of the five gallon samples from each test date was treated with mercuric chloride to inhibit bacterial growth. The untreated 1/13/71 sample became hazy within one day of sampling and eventually formed a precipitate. The treated samples also became hazy, but at a much slower rate. (The refrigerated permeate samples remained clear for weeks after sampling.) The contents of the carboys were used only in the initial chromatographic work to determine the optimum instrument settings and in the preliminary qualitative work. The chromatograms obtained with the treated, untreated and refrigerated samples were similar. Only the refrigerated samples were used for the quantitative work.

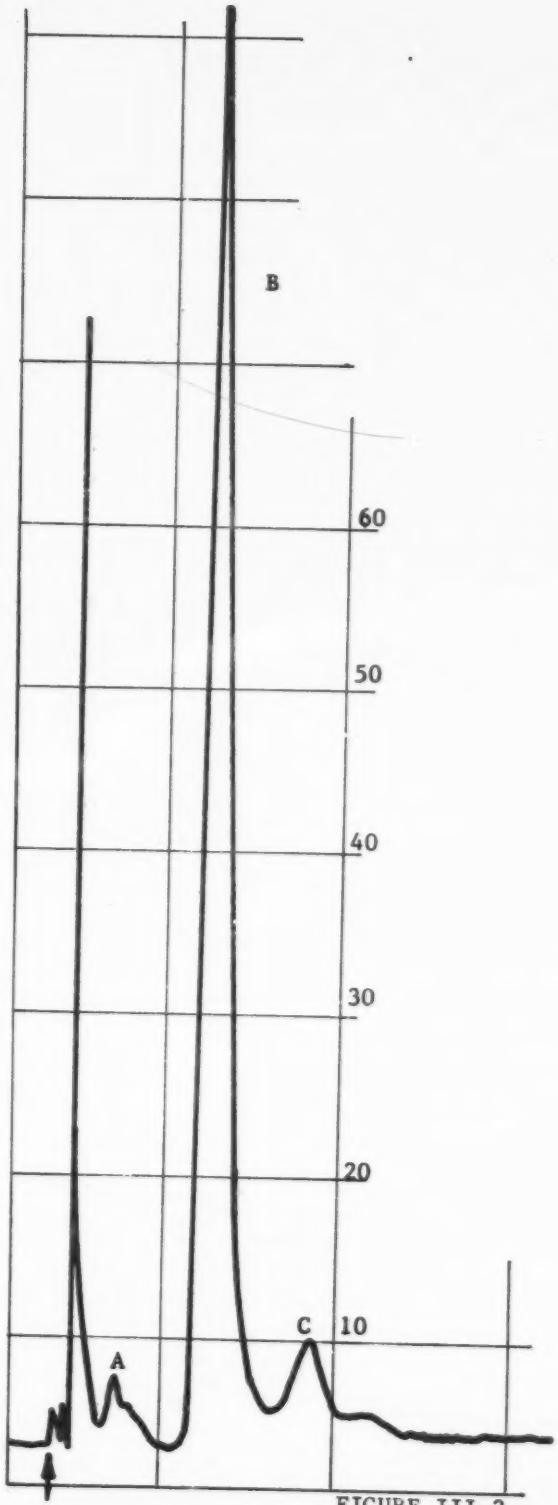
An attempt was made to concentrate the organics in the permeate water by carbon adsorption. A bulk volume of 100 cc Cliffs-Dow (8x32) activated carbon was placed in a 7/8 inch I.D. column. A total of 27 gallons of the 1/13/71 permeate water was passed through the column over a 29.5 hour period. The carbon was drained and dried on a steam bath. A stream of air was used to sweep the evaporated water and volatile organics through a trap maintained at $-18^{o}C$ for recovery of the volatiles. The dry carbon was extracted with chloroform in a soxhlet extractor. Because the samples could be injected directly, further work on the carbon adsorption samples was abandoned. The limitations of the concentrations of low molecular weight organics by carbon adsorption became apparent, however. The uncertainty about the completeness of adsorption of the organics on the carbon and the completeness of extraction from the carbon by the solvent can severely limit the usefulness of any quantitative data obtained. At a later date, carbon isotherm tests performed on a sample of permeate water showed that only 25% of the organic matter (as TOC) was adsorbed by activated carbon. If it is necessary to concentrate low molecular weight organics in the future, it is recommended that a different procedure, such as freeze concentration, be used.

Qualitative Analyses: Chromatograms of the permeate water from the reverse osmosis tests performed on 1/13/71 and 1/20/71 are shown in Figures 1 and 2. For comparison, a chromatogram of distilled water is shown in Figure 3. In each figure, the vertical axis represents the change in detector signal due to the elution of material from the column and the horizontal axis represents time. The arrow indicates the point at which the sample was injected. Comparison of the peaks in Figure 3 with those in the other figures show that the initial peaks are due to the



COLUMN:	Porapak Q
SAMPLE VOLUME:	5 µl
OVEN TEMP.:	140° C
INJECTOR TEMP.:	230° C
DETECTOR TEMP.:	260° C
ATTENUATION:	10

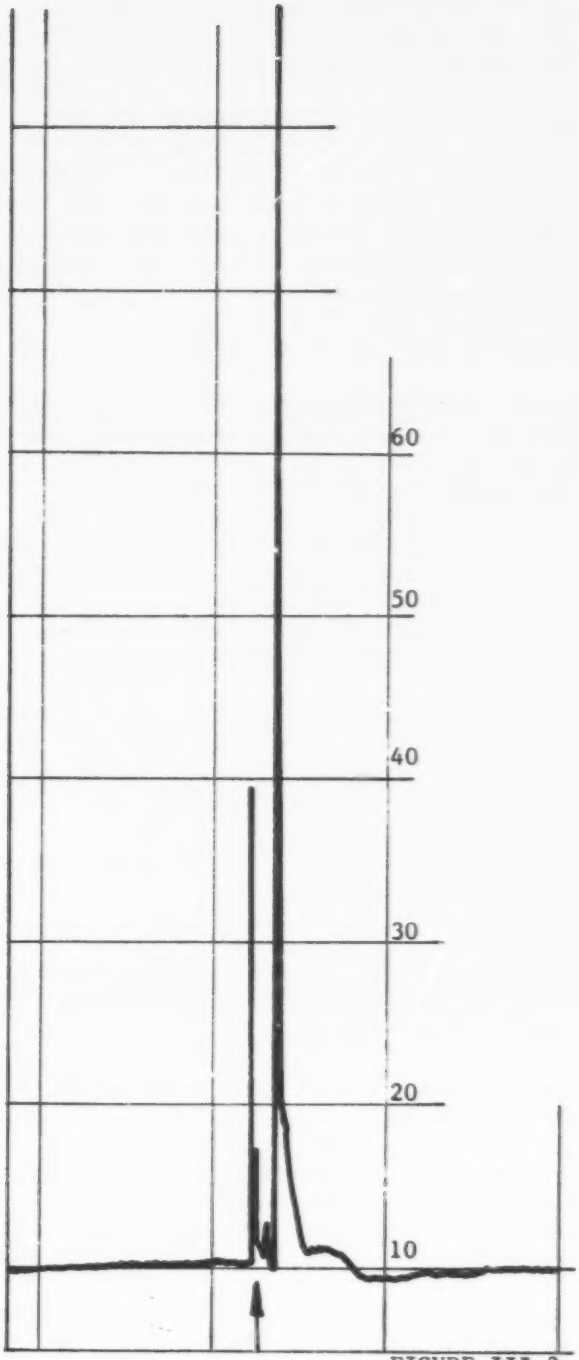
FIGURE III-1
CHROMATOGRAM - RO PERMEATE OF 1/13/71, MILWAUKEE STP



COLUMN:	Porapak Q
SAMPLE VOLUME:	8 µl
OVEN TEMP.:	140° C
INJECTOR TEMP.:	230° C
DETECTOR TEMP.:	260° C
ATTENUATION:	10

FIGURE III-2

CHROMATOGRAM - RO PERMEATE OF 1/20/71, MILWAUKEE STP



COLUMN:	Porapak Q
SAMPLE VOLUME:	5 µl
OVEN TEMP.:	140° C
INJECTOR TEMP.:	230° C
DETECTOR TEMP.:	260° C
ATTENUATION:	10

FIGURE III-3
CHROMATOGRAM - DISTILLED WATER

elution of water from the column. The general appearance of the water peaks was similar to Figure 3 for all tests on the Porapak Q column. Because these peaks are partially due to a sudden pressure change and disruption of the flame rather than to ionization, minor variations in the water peaks occur. For this reason, distilled water was injected periodically during these tests for comparison to the sample peaks.

Comparison of Figures 1 and 3 show that there are three peaks present in Figure 1 not present in Figure 3. These peaks are labeled A, B, and D. There are also three peaks in Figure 2 not present in Figure 3. They are labeled A, B, and C. The peaks labeled A and B in both figures have the same retention time (elute from the column at the same time) and are probably due to the same compounds. Peaks C and D, however, have different retention times, are due to different compounds and are therefore labeled differently. Because of the large size of peak B, the primary objective of the qualitative tests was to identify the compound producing this peak.

The peaks produced by known compounds were compared to the peaks produced by the two permeate samples on both the Porapak Q and the Porapak S columns. On both columns, the ethanol peak matched peak B. An example of the chromatogram produced by injecting a sample of 1/20/71 permeate water on the Porapak S column is shown in Figure 4. In this figure, peak A was obscured by the large water peak and peak C appeared as a shoulder of peak B.

Although the matching of the ethanol peak with peak B does not prove the identity of peak B, some observations can be made that support the conclusion that peak B is probably due to the presence of ethanol:

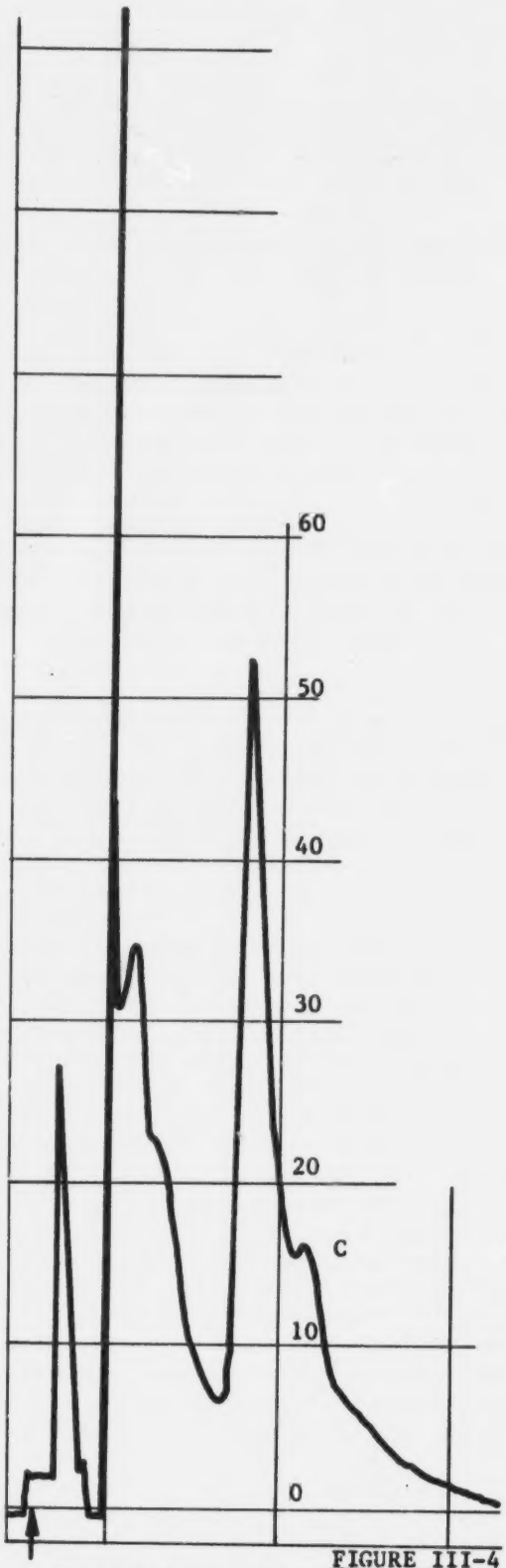
1. Peak B eluted later on the Porapak S column than on the Porapak Q column. Non-polar compounds elute at about the same time from both the Q and the S columns. As compound polarity increases, the elution time increases. The increase in elution time in peak B indicates that the compound producing peak B has a polarity similar to that of alcohols. The compound producing peak C, however, is less polar than peak B.

2. Certain classes of compounds that might be expected to be present in permeate water can be disregarded as possible sources of peak B, because the peaks of certain chemicals belonging to these classes of compounds do not match peak B.

    a. Peak B is not a carboxylic acid. Both formic and acetic acid elute after peak B on Porapak S.

    b. Peak B is probably not an ester. Both methyl acetate and ethyl acetate elute after peak B. The change in elution time between packings Q and S indicate the peak B has a greater polarity than esters.

    c. Peak B is probably not an amine. The secondard and tertiary amines produce peaks that tail badly on Porapak Q. These peaks do not resemble peak B in shape. Both methylamine and ethylamine elute before peak B. Propylamine was not available



COLUMN:	Porapak S
SAMPLE VOLUME:	5 µl
OVEN TEMP.:	175° C
INJECTOR TEMP.:	228° C
DETECTOR TEMP.:	218° C
ATTENUATION:	10

FIGURE III-4
CHROMATOGRAM - RO PERMEATE OF 1/20/71, MILWAUKEE STP

for testing. A Kjeldahl organic nitrogen test showed that a sample of 1/13/71 permeate water contained 3 mg/l organic nitrogen. This amount of organic nitrogen as propylamine would produce a much smaller peak than peak B.

The known compounds that were tested and their liklihood of being present in the permeate waters tested are listed in Table 1.

Although the evidence is strong that peak B was caused by ethanol, further work is recommended to verify this identification. The matching of peak B with the ethanol peak on columns having properties much different than the two Porapak columns used should be sufficient. Columns containing Apiezon L (non-polar) or Carbowax (more polar than the Porapaks) might be used. Material for the preparation of these columns had just been received by the laboratory when the available time for testing ended. Other means of verifying the identity of peak B might be used. The compound producing peak B might be separated by preparative gas chromatography and then identified by colorimetric means (e.g. spot test for alcohols using ceric nitrate) or by other instrumental methods. Such equipment is not available in our laboratory, however.

Some tests were performed on the three foot Porapak Q-S column at temperatures up to 210°C in an effort to detect higher molecular weight materials in the 1/20/71 permeate water. No other peaks of significance were found. Tests were also conducted using the thermal conductivity detector to look for non-organic materials not detected by the flame ionization detector. None were found. It should be pointed out, however, that the conductivity detector is much less sensitive than the ionization detector.

When the qualitative work on the 1/13/71 and 1/20/71 permeate samples was completed, chromatograms of other samples were run to answer some questions concerning the origin and occurrence of the apparent ethanol peak. These chromatograms were run on the Porapak Q column at 140°C to facilitate comparisons and quantitative analysis. Peaks A, B, and C were found in both the feed sample (Figure 5) and the brine sample (Figure 6) from the 1/20/71 reverse osmosis tests. Peak D also appeared in the brine sample. None of these peaks were found however, in the effluent from pilot activated sludge units fed with the brine from the 1/20/71 tests (Figure 7). The possibility that the sewage used in the 1/13/71 and 1/20/71 tests may have been contaminated by the tank truck in which the sewage was brought to the laboratory was considered. Three samples of sewage were obtained from the fine screen house at the Milwaukee sewage plant. A typical chromatogram of these samples is shown in Figure 8. A sample of sewage plant effluent was also chromatographed (Figure 8). Peaks A, B, C and D were found in the raw waste sample; no peaks were found in the effluent sample. It appears that the presence of the compounds producing these peaks is not uncommon in Milwaukee sewage.

Chromatograms of raw sewage from other local sewage plants were also run. No peaks were found in the raw sewage from Menomonee Falls (Figure 9). Peaks A, B, and C were found in the sample from Brookfield (Figure 10). Note that this was run at an instrument sensitivity 3 1/3 times higher

TABLE III-1

KNOWN COMPOUNDS TESTED

Compounds whose peaks do not match peaks A, B, C or D and are therefore concluded to be not responsible for these peaks are as follows:

Formic acid, Acetic acid
Methylamine, Ethylamine
Diethylamine
Triethylamine
Formamide
Ethyl Acetate
1-Propanol, 2-Propanol
Phenol

Compounds which elute at or near peaks A, B, C or D and may possibly be present are:

Methanol - elutes at or near peak A.
Acetone - elutes at or near peak C.
Propionaldehyde - Published tables indicate that this compound also elutes near peak C.
Ethanol - matches peak B in all tests.

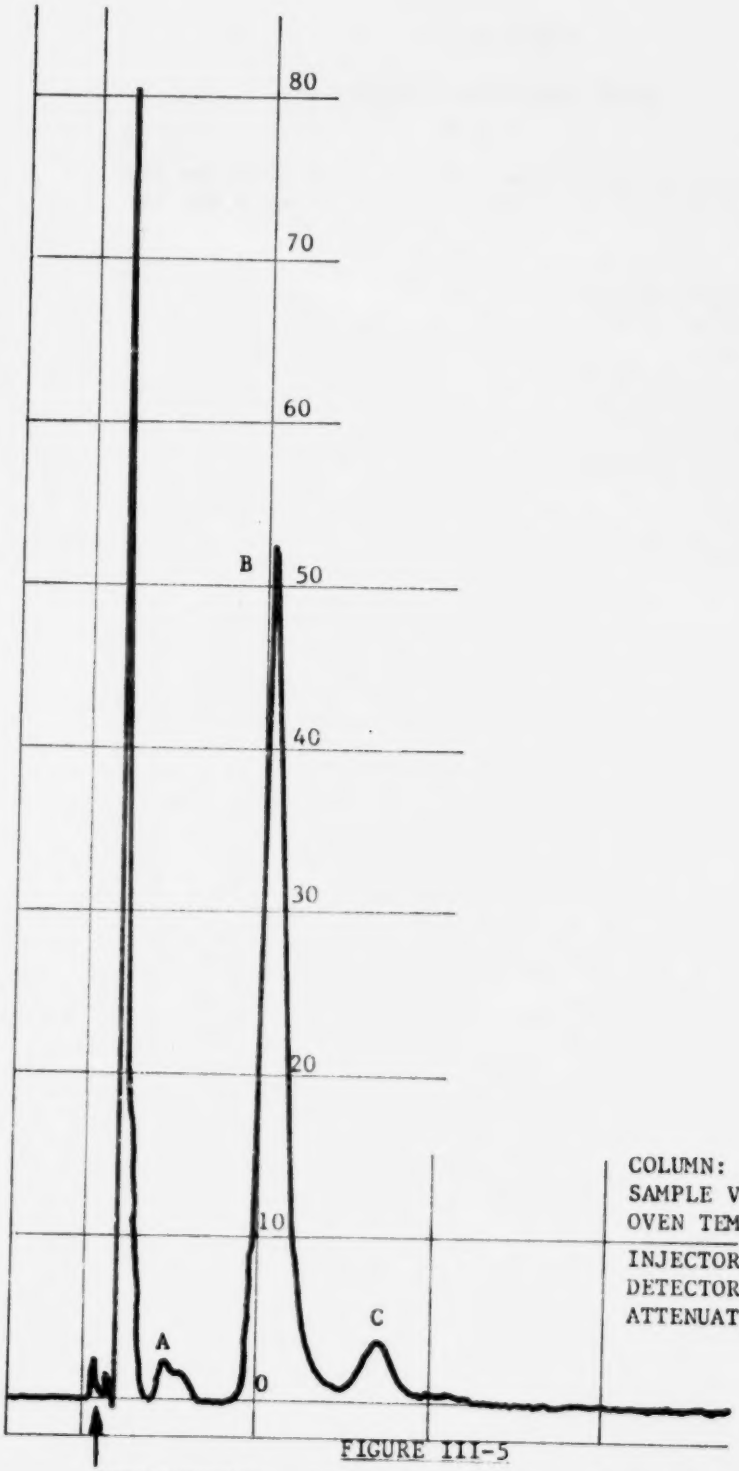


FIGURE III-5

CHROMATOGRAM - RO FEED OF 1/20/71, MILWAUKEE STP

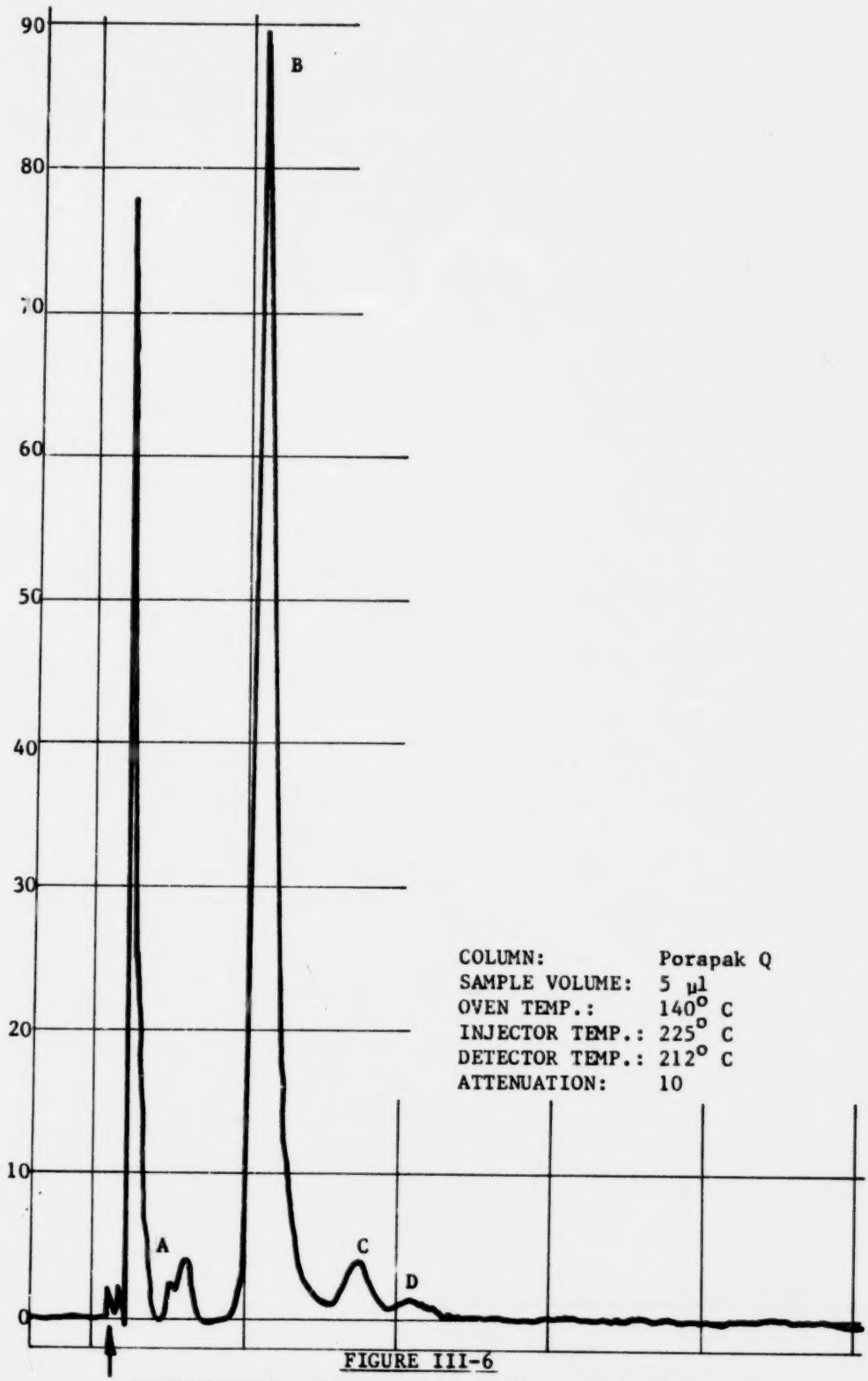
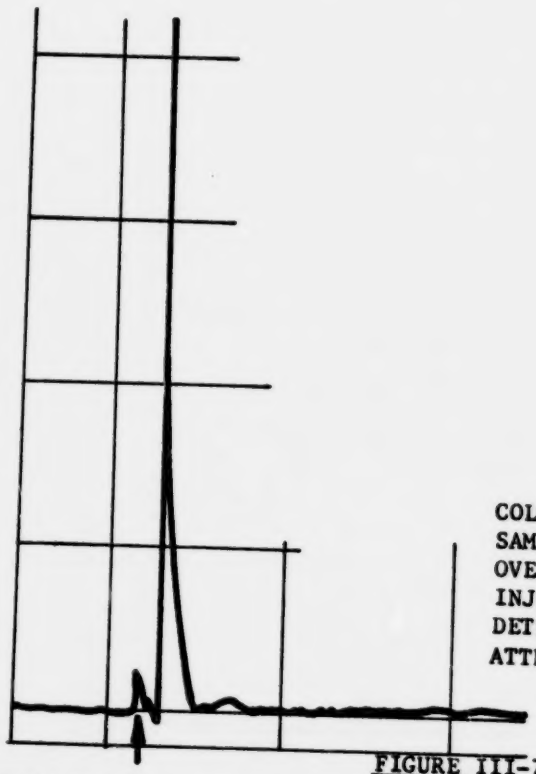


FIGURE III-6

CHROMATOGRAM - RO BRINE OF 1/20/71, MILWAUKEE STP



COLUMN:	Porapak Q
SAMPLE VOLUME:	5 µl
OVEN TEMP.:	140° C
INJECTOR TEMP.:	215° C
DETECTOR TEMP.:	225° C
ATTENUATION:	10

FIGURE III-7

CHROMATOGRAM - BIO-TREATED EFFLUENT OF 1/20/71 RO BRINE, MILWAUKEE STP

COLUMN:	Porapak Q
SAMPLE VOLUME:	5 µl
OVEN TEMP.:	140° C
INJECTOR TEMP.:	200° C
DETECTOR TEMP.:	218° C
ATTENUATION:	10

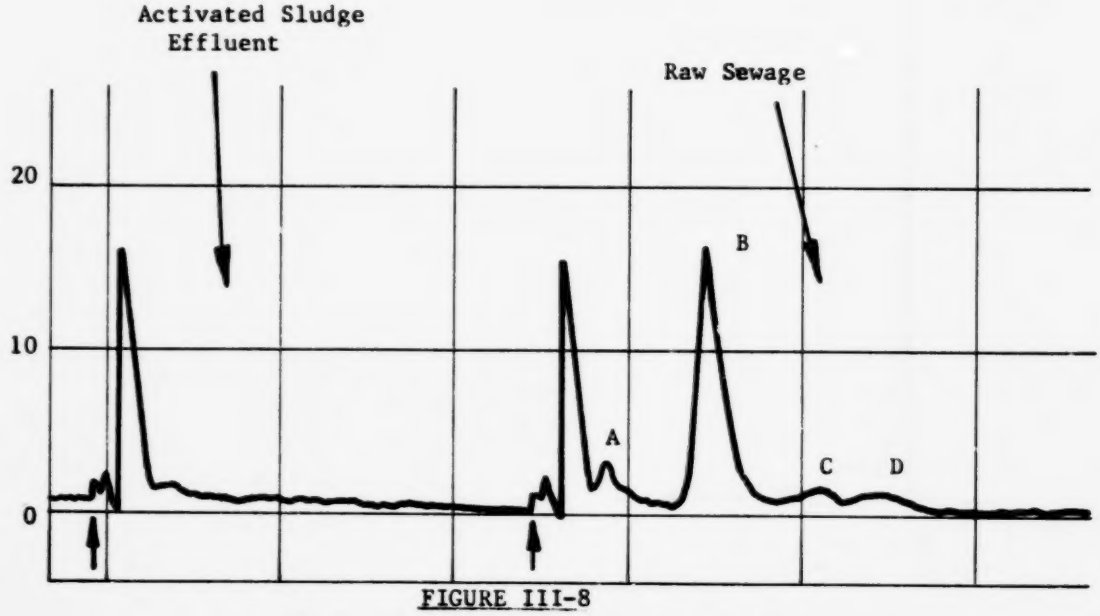
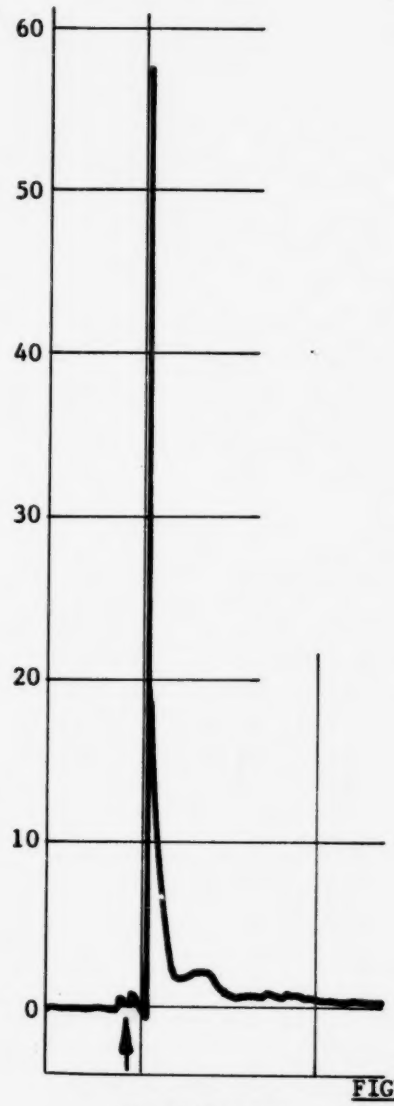


FIGURE III-8

CHROMATOGRAMS - MILWAUKEE STP SAMPLES



COLUMN:	Porapak Q
SAMPLE VOLUME:	5 µl
OVEN TEMP.:	140° C
INJECTOR TEMP.:	212° C
DETECTOR TEMP.:	220° C
ATTENUATION:	10

FIGURE III-9

CHROMATOGRAM - RAW SEWAGE, MENOMONEE FALLS STP

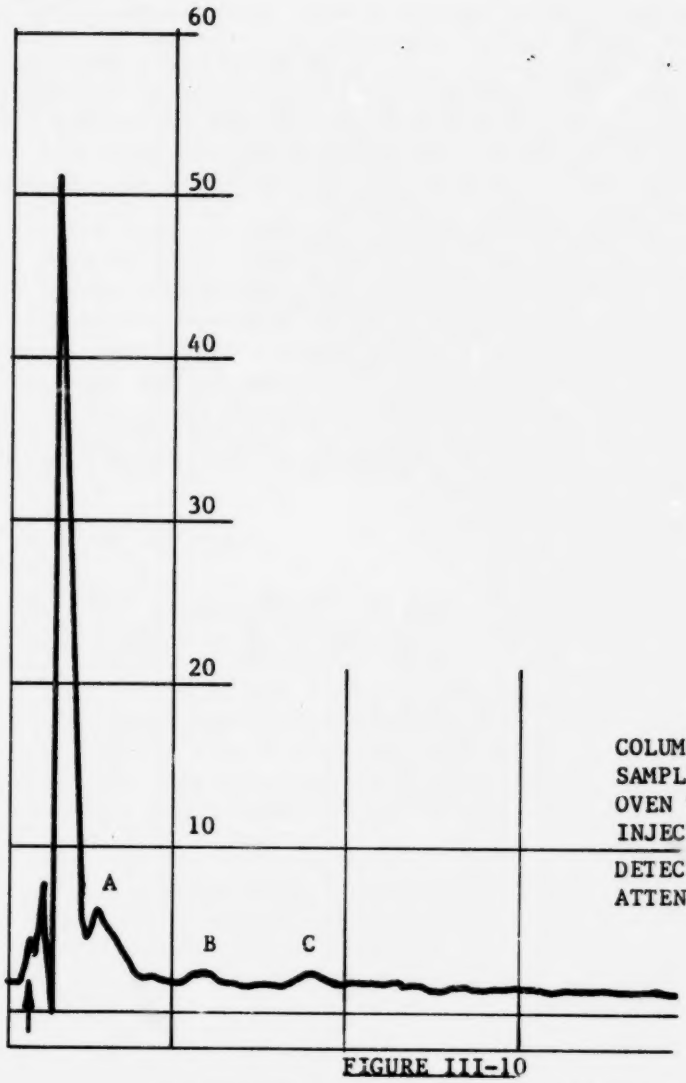


FIGURE III-10

CHROMATOGRAM - RAW SEWAGE, BROOKFIELD STP

than the other chromatograms in order to show peaks B and C more clearly.

The concentration of material producing the apparent ethanol peak and peak C were about the same. A chromatogram of the Kenosha sample is shown in Figure 11. Only a small peak B appeared along with the large peak due to the 1-propanol added as an internal standard. Peaks A, B, C and D were all present in the sample from Racine (Figure 12). It appears that the compounds producing peaks A, B, C and D are neither peculiar to Milwaukee sewage nor are they common to all sewages.

Whereas the permeate water may be expected to contain only low molecular organics, the raw sewage samples contain a much larger range of molecular weight materials. These larger compounds are retained by the Porapak packing at 140°C. When they slowly elute from the column, they show up as "bleed" and produce a wavering base-line, necessitating reconditioning of the column. The peaks in the chromatograms of the raw sewage samples shown in various figures should not be construed to represent all the organics in the sewage. Only the more volatile organics are represented.

Another reverse osmosis test on chemically clarified sewage from Racine, Wisconsin was performed on 3/8/71 to eliminate the effect of high ethanol concentrations in Milwaukee sewage which might have been a result of its brewing industry. The chromatograms of the RO feed and permeate at 45% recovery are shown in Figure 13. All four peaks A, B, C and D appear in both the chromatograms but are very small in magnitude. No predominant peak is noticed. This clearly shows that there is no predominant low molecular weight organic species common to domestic sewages that may be responsible for the poor separation performance of the CA membranes towards soluble organic material.

Quantitative Analysis

The quantitative analysis was performed on the assumption that peak B was caused by ethanol. Both internal standardization using either 1-propanol or 2-propanol and comparison of the sample peak area with the peak area of known amounts of ethanol or 2-propanol were used. When the comparison method was used, standards were injected frequently along with the samples. A check of the two methods showed that they produced similar results. All the quantitative chromatograms were run using the Porapak Q column at 140°C. The amount of samples and standards used varied from 2 µl to 8 µl.

The results of the quantitative analyses are listed in Table 2. Results of the individual injections are listed as an indication of the precision of the measurements. The feed, permeate and brine samples from the 1/20/71 RO tests and the 1/13/71 permeate sample were measured approximately 10 days after sampling. All other samples were measured within one day of the sampling.

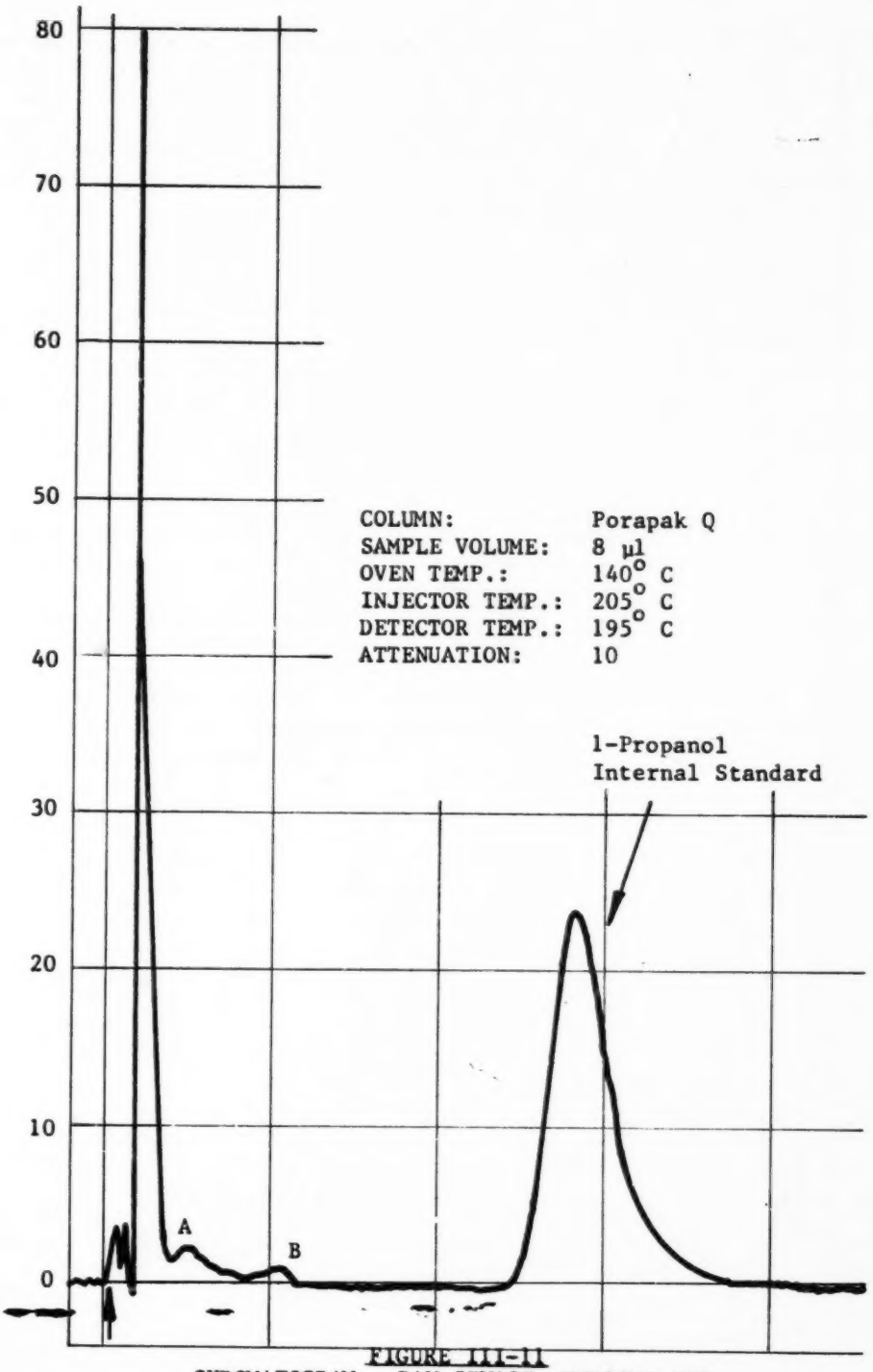


FIGURE III-11
CHROMATOGRAM - RAW SEWAGE, KENOSHA STP

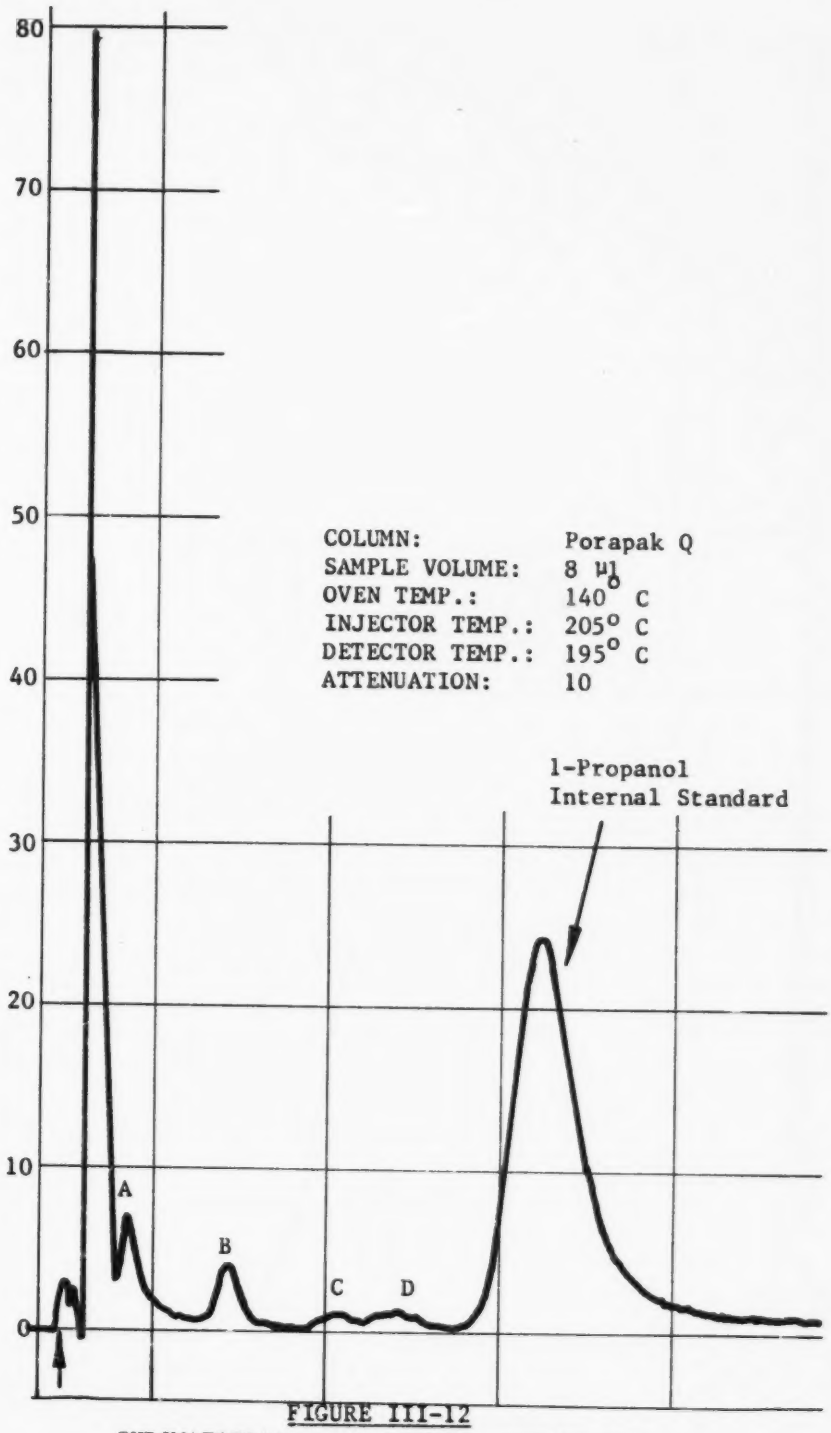


FIGURE III-12
CHROMATOGRAM - RAW SEWAGE, RACINE STP

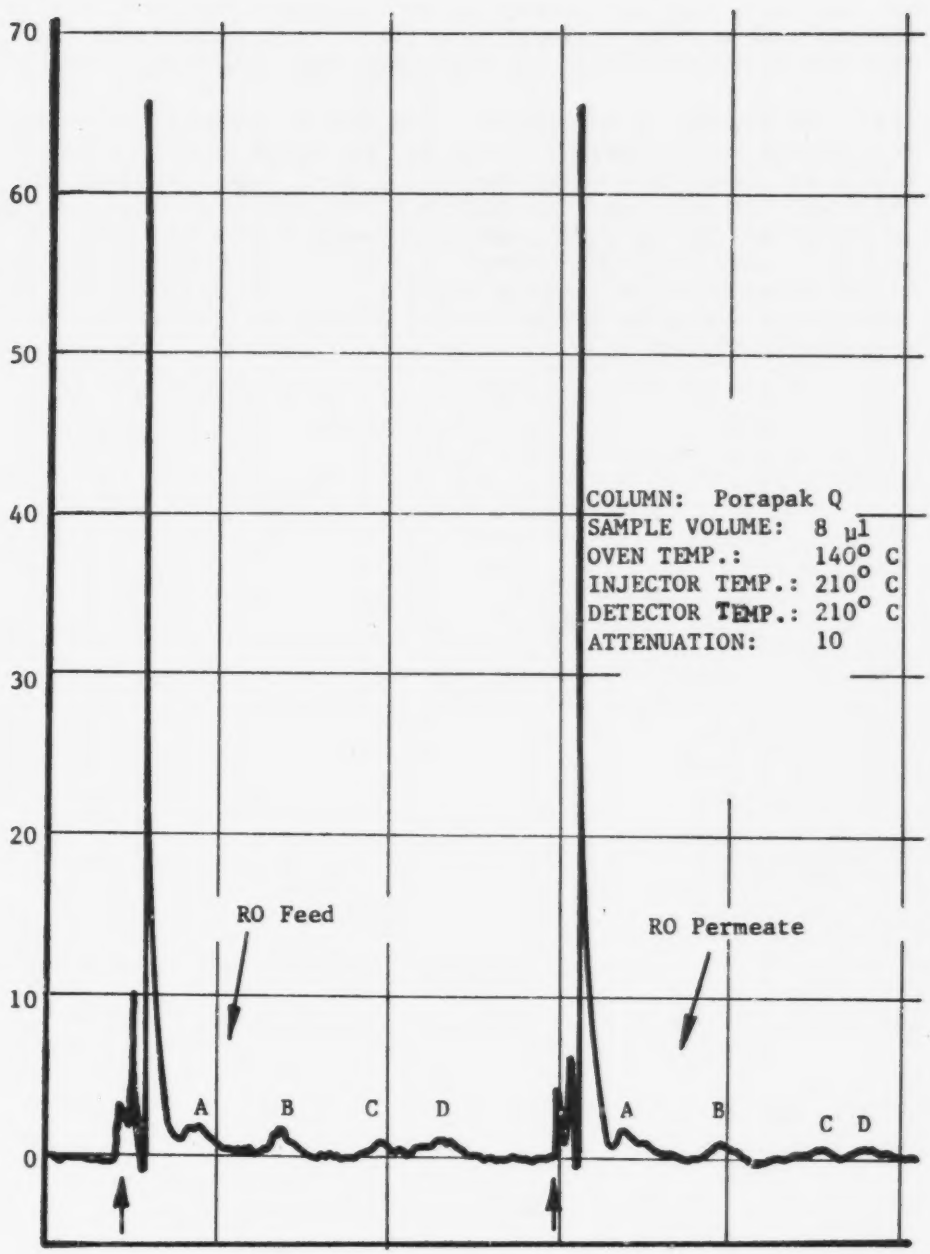


FIGURE III-13

CHROMATOGRAMS - RO FEED AND PERMEATE OF 3/8/71, RACINE STP

Although the quantity of material producing peaks C and D was not measured, a visual comparison of the chromatograms in the various figures shows that the largest of peaks C and D are about the size of Kenosha peak B which measured less than 1 mg/l as ethanol. It is clear that the concentration of the compounds producing peaks C and D is small.

The total organic carbon (TOC) values for the samples that were chromatographed are included in Table 2. For comparison, the TOC values calculated from the average apparent ethanol concentrations are also included. As expected, the portion of the TOC attributable to peak B is small for the raw sewage and feed samples. For the permeate samples at high recovery ratios, however, the TOC calculated from the apparent ethanol concentration accounts for all but 8 to 10 mg/l TOC. It would appear that the major portion of the organic in the permeate are represented by peak B.

TABLE III-2

QUANTITATIVE ANALYSIS RESULTS OF THE LARGEST CHROMATOGRAM - PEAK (B)

Sample Description	Date of Treatment	Treatment Plant	Measured TOC-mg/l	Ave. Area of Peak B - mg/l As Ethanol	Ave. Area of Peak B - mg/l As TOC
Permeate (composite sample @ 90% recovery)	1/13/71	Milwaukee	36	53	28
Feed	1/20/71	Milwaukee	128	45	24
Permeate (composite sample @ 90% recovery)	1/20/71	Milwaukee	38	53	28
Brine @ 90% recovery	1/20/71	Milwaukee	830	162	84
Act. Sl. Effluent - (pilot units on RO brine)	1/20/71	--	75	0	0
Raw Sewage	2/4/71	Milwaukee	272	61	32
Raw Sewage	2/9/71	Milwaukee	108	23	12
Act. Sl. Effluent	2/15/71	Milwaukee	22	0	0
Raw Sewage	2/10/71	Menomonee Falls	41	0	0
Raw Sewage	2/15/71	Brookfield	78	Trace	0
Act. Sl. Effluent	2/15/71	Brookfield	19	0	0
Raw Sewage	2/17/71	Racine	69	6	3
Raw Sewage	2/17/71	Kenosha	44	<1	<0.5
Feed	3/8/71	Racine	39	<2	<1
Permeate - 45% recovery	3/8/71	Racine	9	<2	<1

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16. Abstract

This report documents a laboratory-scale feasibility study for the treatment of domestic sewage. The objective of the study was to produce potable water from chemically clarified sewage via reverse osmosis (RO) and to determine the amenability of the RO concentrate to biological treatment.

Pilot-scale tubular and spiral wound RO units were utilized in this study. It was determined that chemical clarification of the raw sewage was necessary even with the tubular RO systems. The chemicals recommended for the pretreatment (based on jar tests) were ferric chloride and alum. Reverse osmosis produced a water of excellent quality with regard to inorganic ions. However, a significant amount of the dissolved organic materials passed through the cellulose acetate membranes, necessitating further upgrading of product water for potable use. Qualitative investigations on the RO permeate indicated that 70% of the organic matter permeating through the CA membranes from Milwaukee sewage was apparently ethanol (C_2H_5OH).

Bench-scale activated sludge feasibility tests conducted on the RO concentrate indicated that it was feasible to treat it biologically. Soluble TOC removals of 87 to 92% in 4 to 10 hours of aeration along with good settling characteristics for MLSS concentrations up to 6000 mg/l were achieved. A treatment schematic that will provide potable water at 93% recovery and also reduce the pollutional discharge to streams was proposed.

17a. Descriptors

*Reverse Osmosis, *Reverse osmosis concentrates, *Activated sludge, *Tubular reverse osmosis, Domestic sewage, Chemical pretreatment, Water reuse, Economics

17b. Identifiers

Sewage reuse, Reverse osmosis, Concentrate treatment

17c. COWRR Field & Group 05D

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